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Advanced Power and Propulsion: 2000-2004

A Custom Bibliography From the
NASA Scientific and Technical Information Program

October 2004

Advanced Power and Propulsion: 2000-2004

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OCTOBER 2004

20040112040 NASA Glenn Research Center, Cleveland, OH, USA
Performance Expectations of Closed-Brayton-Cycle Heat Exchangers in 100-kWe Nuclear Space Power Systems
Barrett, Michael J.; [2003]; In English, 17-21 Aug. 2003, Portsmouth, VA, USA
Contract(s)/Grant(s): WBS 973-80-10
Report No.(s): AIAA Paper 2003-5956; No Copyright; Avail: CASI; A03, Hardcopy

Performance expectations of closed-Brayton-cycle heat exchangers to be used in 100-k We nuclear space power systems were forecast. Proposed cycle state points for a system supporting a mission to three of Jupiter's moons required effectiveness values for the heat-source exchanger, recuperator and rejection exchanger (gas cooler) of 0.98, 0.95, and 0.97, respectively. Performance parameters such as number of thermal units (Ntu), equivalent thermal conductance (UA), and entropy generation numbers (Ns) varied from 11 to 19, 23 to 39 kW/K, and 0.019 to 0.023 for some standard heat exchanger configurations. Pressure-loss contributions to entropy generation were significant; the largest frictional contribution was 114% of the heat transfer irreversibility. Using conventional recuperator designs, the 0.95 effectiveness proved difficult to achieve without exceeding other performance targets; a metallic, plate-fin counterflow solution called for 15% more mass and 33% higher pressure-loss than the target values. Two types of gas-coolers showed promise. Single-pass counterflow and multipass cross-counterflow arrangements both met the 0.97 effectiveness requirement. Potential reliability-related advantages of the cross-counterflow design were noted. Cycle modifications, enhanced heat transfer techniques and incorporation of advanced materials were suggested options to reduce system development risk. Carbon-carbon sheeting or foam proved an attractive option to improve overall performance.
Author
Performance Prediction; Closed Cycles; Brayton Cycle; Heat Exchangers; Spacecraft Power Supplies; Nuclear Electric Power Generation

20040111041 NASA Marshall Space Flight Center, Huntsville, AL, USA
Space Environments and Effects (SEE) Program: Spacecraft Charging Technology Development Activities
Kauffman, B.; Hardage, D.; Minor, J.; 8th Spacecraft Charging Technology Conference; March 2004; In English; No Copyright; Avail: CASI; A02, Hardcopy

Reducing size and weight of spacecraft, along with demanding increased performance capabilities, introduces many uncertainties in the engineering design community on how materials and spacecraft systems will perform in space. The engineering design community is forever behind on obtaining and developing new tools and guidelines to mitigate the harmful effects of the space environment. Adding to this complexity is the continued push to use Commercial-off-the-Shelf (COTS) microelectronics, potential usage of unproven technologies such as large solar sail structures and nuclear electric propulsion. In order to drive down these uncertainties, various programs are working together to avoid duplication, save what resources are available in this technical area and possess a focused agenda to insert these new developments into future mission designs. This paper will introduce the SEE Program, briefly discuss past and currently sponsored spacecraft charging activities and possible future endeavors.
Author
Spacecraft Charging; NASA Programs; Research and Development

20040086714 NASA Glenn Research Center, Cleveland, OH, USA
The Use of Nuclear Propulsion, Power and 'In-Situ' Resources for Routine Lunar Space Transportation and Commercial Base Development
Borowski, Stanley K.; [2003]; In English, 16-22 Nov. 2003, Waikoloa, HI, USA
Contract(s)/Grant(s): 22-319-30-C2; No Copyright; Avail: CASI; A03, Hardcopy

This viewgraph presentation illustrates possible future strategies for solar system exploration supported by Nuclear Thermal Rocket (NTR) Propulsion. Topics addressed in the presentation include: lunar mining, Liquid Oxygen (LOX) augmented NTR (LANTR), 'Shuttle-Derived' Heavy Lift Vehicle (SDHLV) options for future human Lunar missions, and lunar-produced oxygen (LUNOX).
CASI
Nuclear Propulsion; Space Transportation; Lunar Mining; In Situ Resource Utilization; Space Industrialization

20040084937 Army War Coll., Carlisle Barracks, PA
Isomer Energy Source for Space Propulsion Systems
Johnson, Benjamin L.; Mar. 2004; In English
Report No.(s): AD-A424205; AFIT/GA/ENY/04-M01; No Copyright; Avail: CASI; A07, Hardcopy

Presented in this work are the results of an investigation of alternative means for powering spacecraft and launch vehicles with energy sources other than chemical combustion. Nuclear thermal propulsion and the energy release of a nuclear spin isomer present potential for increased rocket performance with compact, high-energy fuel sources replacing the combustion engines of the Delta IV-H 1st and 2nd stage vehicles. Analysis of historical fission designs along with the isomer hafnium-178-m2 in a particle bed configuration was conducted. Energy storage levels of 1.3 GJ/g are possible with this material, though the successful triggering and maintenance of a chain reaction in this material are still debated topics within the scientific community. The best application for either technology is as an upper stage vehicle with the shielding requirements reduced to that of just a shadow shield between the core and the spacecrafts upper structure. The fission designs are capable of specific impulse values between 800 and 1,000 s leading to mass savings in the range of 7,000 to nearly 10,000 kg once the engine masses and shielding have been included. An isomer core in the configuration of a 19-element PBR may be able to achieve a specific impulse on the order of 880 s with the isomer in metallic form, and specific impulse values as high as 1,090 s if the isomer is in the form of hafnium carbide. This translates to somewhere between a 5,000 and 9,000 kg depending on the material makeup of the core and heat efficiency. Payload mass increases by a factor of two or greater velocity changes are the payoffs of these systems.
DTIC
Aerospace Systems; Isomers; Nuclear Propulsion; Propulsion; Propulsion System Configurations; Propulsion System Performance

20040075687 NASA Marshall Space Flight Center, Huntsville, AL, USA
MSFC Nuclear Propulsion Materials Development
Rogers, J. R.; Cook, B.; [2004]; In English, 4-6 May 2004, Chattanooga, TN, USA; No Copyright; Avail: Other Sources; Abstract Only

Nuclear propulsion systems for spacecraft applications present numerous technical challenges for propulsion systems. They have been the focus of a recent NRA. Challenges inclue: a nuclear reactor subsystem to produce thermal energy; a power conversion subsystem to convert the thermal energy into electrical energy; a propulsion subsystem that utilizes Hall effect thrusters; thruster technologies and high temperature materials to support subsystems. The MSFC Electrostatic Levitation (ESL) Facility provides an ideal platform for the study of high temperature and reactive materials. An overview of the facility and its capabilities will be presented.
Author
Nuclear Propulsion; Research Facilities

20040073503 NASA Marshall Space Flight Center, Huntsville, AL, USA
Basic and Applied Materials Science Research Efforts at MSFC Germane to NASA Goals
Biological and Physical Space Research Laboratory 2002 Science Review; December 2003, 6; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

Presently, a number of investigations are ongoing that blend basic research with engineering applications in support of NASA goals. These include (1) 'Pore Formation and Mobility (PFMI) ' An ISS Glovebox Investigation' NASA Selected Project - 400-34-3D; (2) 'Interactions Between Rotating Bodies' Center Director's Discretionary Fund (CDDF) Project - 279-62-00-16; (3) 'Molybdenum - Rhenium (Mo-Re) Alloys for Nuclear Fuel Containment' TD Collaboration - 800-11-02; (4) 'Fabrication of Alumina - Metal Composites for Propulsion Components' ED Collaboration - 090-50-10; (5) 'Radiation Shielding for Deep-Space Missions' SD Effort; (6) 'Other Research'. In brief, 'Pore Formation and Mobility' is an experiment to be conducted in the ISS Microgravity Science Glovebox that will systematically investigate the development, movement,

and interactions of bubbles (porosity) during the controlled directional solidification of a transparent material. In addition to promoting our general knowledge of porosity physics, this work will serve as a guide to future ISS experiments utilizing metal alloys. ‘Interactions Between Rotating Bodies’ is a CDDF sponsored project that is critically examining, through theory and experiment, claims of ‘new’ physics relating to gravity modification and electric field effects. ‘Molybdenum - Rhenium Alloys for Nuclear Fuel Containment’ is a TD collaboration in support of nuclear propulsion. Mo-Re alloys are being evaluated and developed for nuclear fuel containment. ‘Fabrication of Alumina - Metal Composites for Propulsion Components’ is an ED collaboration with the intent of increasing strength and decreasing weight of metal engine components through the incorporation of nanometer-sized alumina fibers. ‘Radiation Shielding for Deep-Space Missions’ is an SD effort aimed at minimizing the health risk from radiation to human space voyagers; work to date has been primarily programmatic but experiments to develop hydrogen-rich materials for shielding are planned. ‘Other Research’ includes: BUNDLE (Bridgman Unidirectional Dendrite in a Liquid Experiment) activities (primarily crucible development), vibrational float-zone processing (with Vanderbilt University), use of ultrasonics in materials processing (with UAH), rotational effects on microstructural development, and application of magnetic fields for mixing.
Author
Rhenium Alloys; Nuclear Fuels; Aluminum Oxides; Directional Solidification (Crystals); Nuclear Propulsion

20040034798 NASA Glenn Research Center, Cleveland, OH, USA
Project Prometheus
Johnson, Steve; Results of the Workshop on Two-Phase Flow, Fluid Stability and Dynamics: Issues in Power, Propulsion, and Advanced Life Support Systems; December 2003, 71-89; In English; Original contains color illustrations; No Copyright; Avail: CASI; A03, Hardcopy

Project Prometheus will enable a new paradigm in the scientific exploration of the Solar System. The proposed JIMO mission will start a new generation of missions characterized by more maneuverability, flexibility, power and lifetime. Project Prometheus organization is established at NASA Headquarters: 1.Organization established to carry out development of JIMO, nuclear power (radioisotope), and nuclear propulsion research. 2.Completed broad technology and national capacity assessments to inform decision making on planning and technology development. 3.Awarded five NRA s for nuclear propulsion research. 4.Radioisotope power systems in development, and Plutonium-238 being purchased from Russia. 5.Formulated science driven near-term and long-term plan for the safe utilization of nuclear propulsion based missions. 6.Completed preliminary studies (Pre-Phase A) of JIMO and other missions. 7.Initiated JIMO Phase A studies by Contractors and NASA.
Derived from text
Technology Assessment; Prometheus; NASA Space Programs; Nuclear Propulsion; Maneuverability; Decision Making

20040034016 NASA Marshall Space Flight Center, Huntsville, AL, USA
Comparison of Structural Optimization Techniques for a Nuclear Electric Space Vehicle
Benford, Andrew; [2003]; In English, 8-12 Feb. 2004, Albuquerque, NM, USA
Contract(s)/Grant(s): 090-50-EB; No Copyright; Avail: CASI; A02, Hardcopy

The purpose of this paper is to utilize the optimization method of genetic algorithms (GA) for truss design on a nuclear propulsion vehicle. Genetic Algorithms are a guided, random search that mirrors Darwin s theory of natural selection and survival of the fittest. To verify the GA s capabilities, other traditional optimization methods were used to compare the results obtained by the GA’s, first on simple 2-D structures, and eventually on full-scale 3-D truss designs.
Author
Nuclear Propulsion; Genetic Algorithms; Electric Motor Vehicles; Structural Analysis

20040033944 NASA Marshall Space Flight Center, Huntsville, AL, USA
Nuclear Electric Vehicle Optimization Toolset (NEVOT): Integrated System Design Using Genetic Algorithms
Tinker, Michael L.; Steincamp, James W.; Stewart, Eric T.; Patton, Bruce W.; Pannell, William P.; Newby, Ronald L.; Coffman, Mark E.; Qualls, A. L.; Bancroft, S.; Molvik, Greg; [2003]; In English, 8-12 Feb. 2004, Albuquerque, NM, USA
Contract(s)/Grant(s): 090-50-EB; Copyright; Avail: CASI; A02, Hardcopy

The Nuclear Electric Vehicle Optimization Toolset (NEVOT) optimizes the design of all major Nuclear Electric Propulsion (NEP) vehicle subsystems for a defined mission within constraints and optimization parameters chosen by a user. The tool uses a Genetic Algorithm (GA) search technique to combine subsystem designs and evaluate the fitness of the integrated design to fulfill a mission. The fitness of an individual is used within the GA to determine its probability of survival

through successive generations in which the designs with low fitness are eliminated and replaced with combinations or mutations of designs with higher fitness. The program can find optimal solutions for different sets of fitness metrics without modification and can create and evaluate vehicle designs that might never be conceived of through traditional design techniques. It is anticipated that the flexible optimization methodology will expand present knowledge of the design trade-offs inherent in designing nuclear powered space vehicles and lead to improved NEP designs.
Author
Nuclear Electric Propulsion; Optimization; Genetic Algorithms; Systems Engineering; Systems Integration

20040033933 NASA Glenn Research Center, Cleveland, OH, USA
Experimental Investigations From the Operation of a 2 kW Brayton Power Conversion Unit and a Xenon Ion Thruster
Mason, Lee; Birchenough, Arthur; Pinero, Luis; February 2004; In English, 8-12 Feb.2004, Albuquerque, NM, USA
Contract(s)/Grant(s): WBS 22-973-80-10
Report No.(s): NASA/TM-2004-212960; E-14419; No Copyright; Avail: CASI; A03, Hardcopy

A 2 kW Brayton Power Conversion Unit (PCU) and a xenon ion thruster were integrated with a Power Management and Distribution (PMAD) system as part of a Nuclear Electric Propulsion (NEP) Testbed at NASA's Glenn Research Center. Brayton converters and ion thrusters are potential candidates for use on future high power NEP missions such as the proposed Jupiter Icy Moons Orbiter (JIMO). The use of existing lower power test hardware provided a cost-effective means to investigate the critical electrical interface between the power conversion system and ion propulsion system. The testing successfully demonstrated compatible electrical operations between the converter and the thruster, including end-to-end electric power throughput, high efficiency AC to DC conversion, and thruster recycle fault protection. The details of this demonstration are reported herein.
Author
Brayton Cycle; Ion Engines; Nuclear Electric Propulsion; Xenon; Electric Power

20040020226
Nuclear Space Power Systems Materials Requirements
Buckman, R. W., Jr.; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 815-820; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright

High specific energy is required for space nuclear power systems. This generally means high operating temperatures and the only alloy class of materials available for construction of such systems are the refractory metals niobium, tantalum, molybdenum and tungsten. The refractory metals in the past have been the construction materials selected for nuclear space power systems. The objective of this paper will be to review the past history and requirements for space nuclear power systems from the early 1960's through the SP-100 program. Also presented will be the past and present status of refractory metal alloy technology and what will be needed to support the next advanced nuclear space power system. The next generation of advanced nuclear space power systems can benefit from the review of this past experience. Because of a decline in the refractory metal industry in the USA, ready availability of specific refractory metal alloys is limited. [copyright] 2004 American Institute of Physics
Author (AIP)
Alloys; Electric Generators; Molybdenum; Niobium; Nuclear Propulsion; Nuclear Reactors; Reactor Materials; Refractories; Spacecraft Power Supplies; Tantalum; Tungsten

20040020225
Material Requirements, Selection And Development for the Proposed JIMO SpacePower System
Ring, P. J.; Sayre, E. D.; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 806-814; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright

NASA is proposing a major new nuclear Space initiative--The Jupiter Icy Moons Orbiter (JIMO). A mission such as this inevitably requires a significant power source both for propulsion and for on-board power. Three reactor concepts, liquid metal

cooled, heat pipe cooled and gas cooled are being considered together with three power conversion systems Brayton (cycle), Thermoelectric and Stirling cycles, and possibly Photo voltaics for future systems. Regardless of the reactor system selected it is almost certain that high temperature (materials), refractory alloys, will be required. This paper revisits the material selection options, reviewing the rationale behind the SP-100 selection of Nb-1Zr as the major cladding and structural material and considers the alternatives and developments needed for the longer duty cycle of the JIMO power supply. A side glance is also taken at the basis behind the selection of Uranium nitride fuel over UO2 or UC and a brief discussion of the reason for the selection of Lithium as the liquid metal coolant for SP-100 over other liquid metals. [copyright] 2004 American Institute of Physics
Author (AIP)
Cooling; Electric Generators; Heat Transfer; Jupiter (Planet); Liquid Metals; Nuclear Propulsion; Nuclear Reactors; Propulsion; Reactor Materials; Refractories; Spacecraft Power Supplies

20040020224

Performance Analysis of Potassium Heat Pipes Radiator for HP-STMCs Space Reactor Power System

El-Genk, Mohamed S.; Tournier, Jean-Michel; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 793-805; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA
Contract(s)/Grant(s): 1249282; Copyright

A detailed design and performance results of C-C finned, and armored potassium heat pipes radiator for a 110 kWe Heat Pipes-Segmented Thermoelectric Module Converters (HP-STMCs) Space Reactor Power system (SRPS) are presented. The radiator consists of two sections; each serves an equal number of STMCs and has 162 longitudinal potassium heat pipes with 0.508 mm thick C-C fins. The width of the C-C fins at the minor diameter of the radiator is almost zero, but increases with distance along the radiator to reach 3.7 cm at the radiator's major diameter. The radiator's heat pipes (OD = 2. 42 cm in front and 3.03 cm in rear) have thin titanium (0.0762 mm thick) liners and wicks (0.20 mm thick with an effective pore radius of 12-16 [mu]m) and a 1.016 mm thick C-C wall. The wick is separated from the titanium liner by a 0.4 mm annulus filled with liquid potassium to increase the capillary limit. The outer surfaces of the heat pipes in the front and rear sections of the radiator are protected with a C-C armor that is 2.17 mm and 1.70 mm thick, respectively. The inside surface of the heat pipes in the front radiator is thermally insulated while the C-C finned condensers of the rear heat pipes are exposed, radiating into space through the rear opening of the radiator cavity. The heat pipes in both the front and the rear radiators have a 1.5 m long evaporator section and each dissipates 4.47 kW while operating at 43.6% of the prevailing sonic limit. The front and rear radiator sections are 5.29 m and 2.61 m long with outer surface area and mass of 47.1 m2 and 314.3 kg, and 39.9 m2 and 243.2 kg, respectively. The total radiator is 7.63 m long and has minor and major diameters of 1.48 m and 5.57 m, respectively, and a total surface area of 87 m2; however, the effective radiator area, after accounting for heat rejection through the rear of the radiator cavity, is 98.8 m2. The radiator's total mass including the C-C armor is 557.5 kg and the specific area and specific mass are 6.41 kg/m2 and 5.07 kg/kWe, respectively. [copyright] 2004 American Institute of Physics
Author (AIP)
Cooling; Electric Generators; Evaluation; Experiment Design; Finned Bodies; Fission; Heat Pipes; Nuclear Propulsion; Nuclear Reactors; Performance Tests; Potassium; Reliability Analysis; Solar Cells; Solar Generators; Spacecraft Power Supplies; Thermoelectric Generators; Thermoelectric Power Generation

20040020223

Reactor Lithium Heat Pipes for HP-STMCs Space Reactor Power System

Tournier, Jean-Michel; El-Genk, Mohamed S.; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 781-792; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA
Contract(s)/Grant(s): 1249282; Copyright

Design and performance analysis of the nuclear reactor's lithium heat pipes for a 110-kWe Heat Pipes-Segmented Thermoelectric Module Converters (HP-STMCs) Space Reactor Power system (SRPS) are presented. The evaporator length of the heat pipes is the same as the active core height (0.45 m) and the C-C finned condenser is of the same length as the STMC panels (1.5 m). The C-C finned condenser section is radiatively coupled to the collector shoes of the STMCs placed on both

sides. The lengths of the adiabatic section, the values of the power throughput and the evaporator wall temperature depend on the radial location of the heat pipe in the reactor core and the number and dimensions of the potassium heat pipes in the heat rejection radiator. The reactor heat pipes have a total length that varies from 7.57 to 7.73 m, and a 0.2 mm thick Mo-14%Re wick with an average pore radius of 12 [mu]m. The wick is separated from the Mo-14%Re wall by a 0.5 mm annulus filled with liquid lithium, to raise the prevailing capillary limit. The nominal evaporator (or reactor) temperature varies from 1513 to 1591 K and the thermal power of the reactor is 1.6 MW, which averages 12.7 kW for each of the 126 reactor heat pipes. The power throughput per heat pipe increase to a nominal 15.24 kW at the location of the peak power in the core and to 20.31 kW when an adjacent heat pipe fails. The prevailing capillary limit of the reactor heat pipes is 28.3 kW, providing a design margin [greater-than-or-equal, slanted] 28%. [copyright] 2004 American Institute of Physics
Author (AIP)
Cooling; Design Analysis; Electric Generators; Evaluation; Evaporation; Fission; Heat Pipes; Lithium; Nuclear Propulsion; Nuclear Reactors; Performance Tests; Reliability Analysis; Solar Cells; Solar Generators; Spacecraft Power Supplies; Thermoelectric Generators; Thermoelectric Power Generation

20040020220

Thermally Simulated 32kW Direct-Drive Gas-Cooled Reactor: Design, Assembly, and Test

Godfroy, Thomas J.; Kapernick, Richard J.; Bragg-Sitton, Shannon M.; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 757-763; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright

One of the power systems under consideration for nuclear electric propulsion is a direct-drive gas-cooled reactor coupled to a Brayton cycle. In this system, power is transferred from the reactor to the Brayton system via a circulated closed loop gas. To allow early utilization, system designs must be relatively simple, easy to fabricate, and easy to test using non-nuclear heaters to closely mimic heat from fission. This combination of attributes will allow pre-prototypic systems to be designed, fabricated, and tested quickly and affordably. The ability to build and test units is key to the success of a nuclear program, especially if an early flight is desired. The ability to perform very realistic non-nuclear testing increases the success probability of the system. In addition, the technologies required by a concept will substantially impact the cost, time, and resources required to develop a successful space reactor power system. This paper describes design features, assembly, and test matrix for the testing of a thermally simulated 32kW direct-drive gas-cooled reactor in the Early Flight Fission -- Test Facility (EFF-TF) at Marshall Space Flight Center. The reactor design and test matrix are provided by Los Alamos National Laboratories. [copyright] 2004 American Institute of Physics
Author (AIP)
Assembling; Brayton Cycle; Cooling; Electric Generators; Fission; Gas Cooled Reactors; Gas Mixtures; Helium; Mechanical Drives; Nuclear Electric Propulsion; Nuclear Fission; Nuclear Reactors; Propulsion; Reactor Design; Spacecraft Power Supplies; Tests; Xenon

20040020218

Single Channel Testing for Characterization of the Direct Gas Cooled Reactor and the SAFE-100 Heat Exchanger

Bragg-Sitton, S. M.; Kapernick, R.; Godfroy, T. J.; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 741-748; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright

Experiments have been designed to characterize the coolant gas flow in two space reactor concepts that are currently under investigation by NASA Marshall Space Flight Center and Los Alamos National Laboratory: the direct-drive gas-cooled reactor (DDG) and the SAFE-100 heatpipe-cooled reactor (HPR). For the DDG concept, initial tests have been completed to measure pressure drop versus flow rate for a prototypic core flow channel, with gas exiting to atmospheric pressure conditions. The experimental results of the completed DDG tests presented in this paper validate the predicted results to within a reasonable margin of error. These tests have resulted in a re-design of the flow annulus to reduce the pressure drop. Subsequent tests will be conducted with the re-designed flow channel and with the outlet pressure held at 150 psi (1 MPa). Design of a similar test for a nominal flow channel in the HPR heat exchanger (HPR-HX) has been completed and hardware is currently being assembled for testing this channel at 150 psi. When completed, these test programs will provide the data necessary to

validate calculated flow performance for these reactor concepts (pressure drop and film temperature rise). [copyright] 2004 American Institute of Physics
Author (AIP)
Cooling; Electric Generators; Fission; Gas Cooled Reactors; Gas Flow; Gas Mixtures; Heat Exchangers; Heat Pipes; Mechanical Drives; Nuclear Propulsion; Nuclear Reactors; Spacecraft Power Supplies; Tests

20040020214
Early Flight Fission Test Facilities (EFF-TF) To Support Near-Term Space Fission Systems
Van Dyke, Melissa; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 713-719; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright

Through hardware based design and testing, the EFF-TF investigates fission power and propulsion component, subsystems, and integrated system design and performance. Through demonstration of systems concepts (designed by Sandia and Los Alamos National Laboratories) in relevant environments, previous non-nuclear tests in the EFF-TF have proven to be a highly effective method (from both cost and performance standpoint) to identify and resolve integration issues. Ongoing research at the EFF-TF is geared towards facilitating research, development, system integration, and system utilization via cooperative efforts with DOE labs, industry, universities, and other NASA centers. This paper describes the current efforts for 2003. [copyright] 2004 American Institute of Physics
Author (AIP)
Aerospace Systems; Component Reliability; Cooling; Electric Generators; Fission; Flight Tests; Gases; Heat Pipes; Liquid Metals; Nuclear Fission; Nuclear Propulsion; Nuclear Reactors; Propulsion System Performance; Reactor Design; Spacecraft Power Supplies; Support Systems; Systems Engineering; Test Facilities

20040020213
Overview of Fuel Rod Simulator Usage at ORNL
Ott, Larry J.; McCulloch, Reg; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 703-712; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA
Contract(s)/Grant(s): DE-AC05-00OR22725; Copyright

During the 1970s and early 1980s, the Oak Ridge National Laboratory (ORNL) operated large out-of-reactor experimental facilities to resolve thermal-hydraulic safety issues in nuclear reactors. The fundamental research ranged from material mechanical behavior of fuel cladding during the depressurization phase of a loss-of-coolant accident (LOCA) to basic heat transfer research in gas- or sodium-cooled cores. The largest facility simulated the initial phase (less than 1 min. of transient time) of a LOCA in a commercial pressurized-water reactor. The nonnuclear reactor cores of these facilities were mimicked via advanced, highly instrumented electric fuel rod simulators locally manufactured at ORNL. This paper provides an overview of these experimental facilities with an emphasis on the fuel rod simulators. [copyright] 2004 American Institute of Physics
Author (AIP)
Electric Generators; Fissile Fuels; Heating; Hydraulic Equipment; Nuclear Fuel Elements; Nuclear Propulsion; Nuclear Reactors; Reactor Safety; Research Facilities; Simulation; Spacecraft Power Supplies; Test Facilities

20040020212
Test Facilities and Experience on Space Nuclear System Developments at the Kurchatov Institute
Ponomarev-Stepnoi, Nikolai N.; Garin, Vladimir P.; Glushkov, Evgeny S.; Kompaniets, George V.; Kukharkin, Nikolai E.; Madeev, Vicktor G.; Papin, Vladimir K.; Polyakov, Dmitry N.; Stepennov, Boris S.; Tchuniyaev, Yevgeny I.; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 696-702; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright

The complexity of space fission systems and rigidity of requirement on minimization of weight and dimension characteristics along with the wish to decrease expenditures on their development demand implementation of experimental works which results shall be used in designing, safety substantiation, and licensing procedures. Experimental facilities are intended to solve the following tasks: obtainment of benchmark data for computer code validations, substantiation of design solutions when computational efforts are too expensive, quality control in a production process, and 'iron' substantiation of criticality safety design solutions for licensing and public relations. The NARCISS and ISKRA critical facilities and unique ORM facility on shielding investigations at the operating OR nuclear research reactor were created in the Kurchatov Institute to solve the mentioned tasks. The range of activities performed at these facilities within the implementation of the previous Russian nuclear power system programs is briefly described in the paper. This experience shall be analyzed in terms of methodological approach to development of future space nuclear systems (this analysis is beyond this paper). Because of the availability of these facilities for experiments, the brief description of their critical assemblies and characteristics is given in this paper. [copyright] 2004 American Institute of Physics
Author (AIP)
Aerospace Systems; Computer Techniques; Diagnosis; Electric Generators; Nuclear Fission; Nuclear Propulsion; Nuclear Reactors; Optimization; Reactor Design; Reactor Materials; Shielding; Spacecraft Power Supplies; Test Facilities

20040020211
Engineering and Fabrication Considerations for Cost-Effective Space Reactor Shield Development
Berg, Thomas A.; Disney, Richard K.; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 688-695; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA
Contract(s)/Grant(s): DE-AC05-00OR-22800; Copyright
Investment in developing nuclear power for space missions cannot be made on the basis of a single mission. Current efforts in the design and fabrication of the reactor module, including the reactor shield, must be cost-effective and take into account scalability and fabricability for planned and future missions. Engineering considerations for the shield need to accommodate passive thermal management, varying radiation levels and effects, and structural/mechanical issues. Considering these challenges, design principles and cost drivers specific to the engineering and fabrication of the reactor shield are presented that contribute to lower recurring mission costs. [copyright] 2004 American Institute of Physics
Author (AIP)
Cost Effectiveness; Electric Generators; Engineering; Management; Nuclear Fission; Nuclear Propulsion; Nuclear Reactors; Product Development; Reactor Design; Reactor Materials; Shielding; Space Missions; Spacecraft Power Supplies

20040020209
Space Fission System Test Effectiveness
Houts, Mike; Schmidt, Glen L.; Van Dyke, Melissa; Godfroy, Tom; Martin, James; Bragg-Sitton, Shannon; Dickens, Ricky; Salvail, Pat; Harper, Roger; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 673-679; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright
Space fission technology has the potential to enable rapid access to any point in the solar system. If fission propulsion systems are to be developed to their full potential, however, near-term customers need to be identified and initial fission systems successfully developed, launched, and utilized. One key to successful utilization is to develop reactor designs that are highly testable. Testable reactor designs have a much higher probability of being successfully converted from paper concepts to working space hardware than do designs which are difficult or impossible to realistically test. 'Test Effectiveness' is one measure of the ability to realistically test a space reactor system. The objective of this paper is to discuss test effectiveness as applied to the design, development, flight qualification, and acceptance testing of space fission systems. The ability to perform highly effective testing would be particularly important to the success of any near-term mission, such as NASA's Jupiter Icy Moons Orbiter, the first mission under study within NASA's Project Prometheus, the Nuclear Systems Program. [copyright] 2004 American Institute of Physics
Author (AIP)
Aerospace Engineering; Cooling; Electric Generators; Fission; Nuclear Propulsion; Nuclear Reactors; Propulsion; Solar System; Spacecraft Power Supplies; System Effectiveness; Test Facilities

20040020208

Conceptual Design of HP-STMCs Space Reactor Power System for 110 kWe

El-Genk, Mohamed S.; Tournier, Jean-Michel; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 658-672; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright

A conceptual design of a Heat Pipe-Segmented Thermoelectric Module Converters (HP-STMCs) space reactor power system (SRPS) for a net power of 110 kWe is developed. The parametric analysis changed the number of radiator's potassium heat pipes from 224 to 336 and calculated the effects on the operation parameters and total mass of the system. The reactor has a hexagonal core comprised of 126 heat pipe modules, each consists of three UN, 1.5 cm OD fuel pins brazed to a central lithium heat pipe of identical diameter. The Re cladding of the fuel pins is brazed along the active core length to the lithium heat pipe using 6 Re tri-cusps. The reactor control is accomplished using 12 B4C/BeO control drums, a large diameter one on each side of the hexagonal core and a small diameter one at each corner. The control drums are placed within the radial BeO reflector (7.1-9.1 cm thick). The fuel pin peak-to-average power ratio in the reactor core is 1. 12-1.19. Despite its very high density and fabrication challenge, using rhenium structure in the reactor core is necessary for three main reasons: (a) the high reactor temperature ([greater-than-or-equal, slanted] 1500 K) (b) excellent compatibility with the UN fuel and lithium; (c) to cause a spectrum shift that ensures having sufficient negative reactivity margin during a water submersion accident. The reference HP-STMC system with 324, 2.42-3.03 cm OD potassium heat pipes in the radiator is 9.60 m long and has a cone angle of 30[deg]. The nominal operation of the reactor's lithium heat pipes and of the radiator's potassium heat pipes is at or below [approx] 45% of the prevailing wicking and sonic limit, respectively. The masses of the reactor and radiation shadow shield are 753.7 kg and 999.5 kg, respectively; the average heat pipes temperature in the reactor is 1513 K; the mass of the reactor's lithium heat pipes with a C-C finned condenser that is 1.5 m long is 516.1 kg; the mass of the radiator is 557.5 kg, with an outer surface area of 87 m2 (6.41 kg/m2) and effective temperatures of 752 K and 734 K for the front and rear radiator sections, respectively. These estimates are for a constant collector temperature for the STMCs of 1300 K and STMCs' thermal and electrical losses of 5% and 8%, respectively. The estimates of the total mass and specific power of the reference HP-STMCs SRPS, pending future detailed design and analysis, are 4261 kg and 25.8 We/kg, respectively. [copyright] 2004 American Institute of Physics

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Electric Generators; Fuels; Heat Pipes; Lithium; Mass; Nuclear Fission; Nuclear Propulsion; Nuclear Reactors; Parameter Identification; Potassium; Radiation Protection; Reactor Design; Solar Cells; Solar Generators; Spacecraft Power Supplies; Temperature Distribution; Thermoelectric Generators; Thermoelectric Power Generation

20040020205

Autonomous Control Capabilities for Space Reactor Power Systems

Wood, Richard T.; Neal, John S.; Brittain, C. Ray; Mullens, James A.; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 631-638; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA

Contract(s)/Grant(s): DE-AC05-00OR22725; Copyright

The National Aeronautics and Space Administration's (NASA's) Project Prometheus, the Nuclear Systems Program, is investigating a possible Jupiter Icy Moons Orbiter (JIMO) mission, which would conduct in-depth studies of three of the moons of Jupiter by using a space reactor power system (SRPS) to provide energy for propulsion and spacecraft power for more than a decade. Terrestrial nuclear power plants rely upon varying degrees of direct human control and interaction for operations and maintenance over a forty to sixty year lifetime. In contrast, an SRPS is intended to provide continuous, remote, unattended operation for up to fifteen years with no maintenance. Uncertainties, rare events, degradation, and communications delays with Earth are challenges that SRPS control must accommodate. Autonomous control is needed to address these challenges and optimize the reactor control design. In this paper, we describe an autonomous control concept for generic SRPS designs. The formulation of an autonomous control concept, which includes identification of high-level functional requirements and generation of a research and development plan for enabling technologies, is among the technical activities that are being conducted under the U.S. Department of Energy's Space Reactor Technology Program in support of the NASA's

Project Prometheus. The findings from this program are intended to contribute to the successful realization of the JIMO mission. [copyright] 2004 American Institute of Physics
Author (AIP)
Aerospace Systems; Automatic Control; Control Theory; Electric Generators; Jupiter (Planet); Jupiter Satellites; NASA Programs; Nuclear Propulsion; Nuclear Reactor Control; Nuclear Reactors; Optimization; Propulsion; Solar Cells; Solar Generators; Spacecraft Power Supplies; Systems Analysis

20040020203

Reactor Start-up and Control Methodologies: Consideration of the Space Radiation Environment

Bragg-Sitton, Shannon M.; Holloway, James Paul; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 614-622; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA
Contract(s)/Grant(s): DE-FG07-02SF22612; Copyright

The use of fission energy in space power and propulsion systems offers considerable advantages over chemical propulsion. Fission provides over six orders of magnitude higher energy density, which translates to higher vehicle specific impulse and lower specific mass. These characteristics enable the accomplishment of ambitious space exploration missions. The natural radiation environment in space provides an external source of protons and high energy, high Z particles that can result in the production of secondary neutrons through interactions in reactor structures. Initial investigation using MCNPX 2.5.b for proton transport through the SAFE-400 reactor indicates a secondary neutron net current of 1.4 x107 n/s at the core-reflector interface, with an incoming current of 3.4 x106 n/s due to neutrons produced in the Be reflector alone. This neutron population could provide a reliable startup source for a space reactor. Additionally, this source must be considered in developing a reliable control strategy during reactor startup, steady-state operation, and power transients. An autonomous control system is developed and analyzed for application during reactor startup, accounting for fluctuations in the radiation environment that result from changes in vehicle location (altitude, latitude, position in solar system) or due to temporal variations in the radiation field, as may occur in the case of solar flares. One proposed application of a nuclear electric propulsion vehicle is in a tour of the Jovian system, where the time required for communication to Earth is significant. Hence, it is important that a reactor control system be designed with feedback mechanisms to automatically adjust to changes in reactor temperatures, power levels, etc., maintaining nominal operation without user intervention. This paper will evaluate the potential use of secondary neutrons produced by proton interactions in the reactor vessel as a startup source for a space reactor and will present a potential control methodology for reactor startup procedures in the event of source fluctuations. [copyright] 2004 American Institute of Physics
Author (AIP)
Aerospace Environments; Chemical Propulsion; Control Theory; Electric Generators; Electric Propulsion; Environment Effects; Extraterrestrial Radiation; Neutrons; Nuclear Propulsion; Nuclear Reactor Control; Nuclear Reactors; Propulsion System Configurations; Propulsion System Performance; Radiation Effects; Secondary Emission; Spacecraft Power Supplies

20040020199

Direct Estimation of Power Distribution in Reactors for Nuclear Thermal Space Propulsion

Aldemir, Tunc; Miller, Don W.; Burghelea, Andrei; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 582-589; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright

A recently proposed constant temperature power sensor (CTPS) has the capability to directly measure the local power deposition rate in nuclear reactor cores proposed for space thermal propulsion. Such a capability reduces the uncertainties in the estimated power peaking factors and hence increases the reliability of the nuclear engine. The CTPS operation is sensitive to the changes in the local thermal conditions. A procedure is described for the automatic on-line calibration of the sensor through estimation of changes in thermal .conditions. [copyright] 2004 American Institute of Physics
Author (AIP)
Finite Difference Theory; Nuclear Propulsion; Nuclear Reactors; Power Reactors; Propulsion; Reactor Cores; Spacecraft; Temperature Distribution; Temperature Sensors

20040020182

Status of Fuel Development and Manufacturing for Space Nuclear Reactors at BWX Technologies

Carmack, W. J.; Husser, D. L.; Mohr, T. C.; Richardson, W. C.; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 426-431; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright

New advanced nuclear space propulsion systems will soon seek a high temperature, stable fuel form. BWX Technologies Inc (BWXT) has a long history of fuel manufacturing. UO2, UCO, and UCx have been fabricated at BWXT for various US and international programs. Recent efforts at BWXT have focused on establishing the manufacturing techniques and analysis capabilities needed to provide a high quality, high power, compact nuclear reactor for use in space nuclear powered missions. To support the production of a space nuclear reactor, uranium nitride has recently been manufactured by BWXT. In addition, analytical chemistry and analysis techniques have been developed to provide verification and qualification of the uranium nitride production process. The fabrication of a space nuclear reactor will require the ability to place an unclad fuel form into a clad structure for assembly into a reactor core configuration. To this end, BWX Technologies has reestablished its capability for machining, GTA welding, and EB welding of refractory metals. Specifically, BWX Technologies has demonstrated GTA welding of niobium flat plate and EB welding of niobium and Nb-1Zr tubing. In performing these demonstration activities, BWX Technologies has established the necessary infrastructure to manufacture UO2, UCx, or UNx fuel, components, and complete reactor assemblies in support of space nuclear programs. [copyright] 2004 American Institute of Physics

Author (AIP)

Aerospace Engineering; Electric Generators; Fuels; High Temperature; Nitrogen Compounds; Nuclear Propulsion; Nuclear Reactors; Propulsion; Spacecraft; Spacecraft Power Supplies; Systems Engineering; Uranium Compounds

20040020180

Nuclear Thermal Rocket -- An Established Space Propulsion Technology

Klein, Milton; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 413-419; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, NM, USA; Copyright

From the late 1950s to the early 1970s a major program successfully developed the capability to conduct space exploration using the advanced technology of nuclear rocket propulsion. The program had two primary elements: pioneering and advanced technology work--Rover--at Los Alamos National Laboratory and its contractors provided the basic reactor design, fuel materials development, and reactor testing capability; and engine development--NERVA--by the industrial team of Aerojet and Westinghouse building on and extending the Los Alamos efforts to flight system development. This presentation describes the NERVA program, the engine system testing that demonstrated the space-practical operation capabilities of nuclear thermal rockets, and the mission studies that point the way to most effectively use the NTR capabilities. Together, the two programs established a technology base that includes proven NTR capabilities of (1) over twice the specific impulse of chemical propulsion systems, (2) thrust capabilities ranging from 44kN to 1112kN, and (3) practical thrust-to-weight ratios for future NASA space exploration missions, both manned payloads to Mars and unmanned payloads to the outer planets. The overall nuclear rocket program had a unique management structure that integrated the efforts of the two government agencies involved--NASA and the then-existing Atomic Energy Commission. The objective of this paper is to summarize and convey the technical and management lessons learned in this program as the nation considers the design of its future space exploration activities. [copyright] 2004 American Institute of Physics

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Aerospace Engineering; Electric Propulsion; Nuclear Propulsion; Propulsion; Research Projects; Space Exploration; Spacecraft

20040020176

Estimation of Specific Mass for Multimegawatt NEP Systems Based on Vapor Core Reactors with MHD Power Conversion

Knight, Travis; Anghaie, Samim; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 379-387; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New

Mexico, USA; Copyright

Very low specific-mass power generation in space is possible using Vapor Core Reactors with Magnetohydrodynamic (VCR/MHD) generator. These advanced reactors at the conceptual design level have potential for the generation of tens to hundreds of megawatts of power in space with specific mass of about 1 kg/kWe. Power for nuclear electric propulsion (NEP) is possible with almost direct power conditioning and coupling of the VCR/MHD power output to the VASIMR engine, MPD, and a whole host of electric thrusters. The VCR/MHD based NEP system is designed to power space transportation systems that dramatically reduce the mission time for human exploration of the entire solar system or for aggressive long-term robotic missions. There are more than 40 years of experience in the evaluation of the scientific and technical feasibility of gas and vapor core reactor concepts. The proposed VCR is based on the concept of a cavity reactor made critical through the use of a reflector such as beryllium or beryllium oxide. Vapor fueled cavity reactors that are considered for NEP applications operate at maximum core center and wall temperatures of 4000 K and 1500K, respectively. A recent investigation has resulted in the conceptual design of a uranium tetrafluoride fueled vapor core reactor coupled to a MHD generator. Detailed neutronic design and cycle analyses have been performed to establish the operating design parameters for 10 to 200 MWe NEP systems. An integral system engineering-simulation code is developed to perform parametric analysis and design optimization studies for the VCR/MHD power system. Total system weight and size calculated based on existing technology has proven the feasibility of achieving exceptionally low specific mass ([alpha] [approx]1 kg/kWe) with a VCR/MHD powered system. [copyright] 2004 American Institute of Physics

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Electric Propulsion; Flux (Rate); Ion Engines; Magnetohydrodynamic Generators; Magnetohydrodynamics; Neutrons; Plasmas (Physics); Propulsion; Radiation Protection; Spacecraft; Temperature

20040020175

Preliminary Comparison Between Nuclear-Electric and Solar-Electric Propulsion Systems for Future Mars Missions

Koppel, Christophe R.; Valentian, Dominique; Latham, Paul; Fearn, David; Bruno, Claudio; Nicolini, David; Roux, Jean-Pierre; Paganucci, F.; Saverdi, Massimo; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 369-378; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright

Recent US and European initiatives in Nuclear Propulsion lend themselves naturally to raising the question of comparing various options and particularly Nuclear Electric Propulsion (NEP) with Solar Electric Propulsion (SEP). SEP is in fact mentioned in one of the latest versions of the NASA Mars Manned Mission as a possible candidate. The purpose of this paper is to compare NEP, for instance, using high power MPD, Ion or Plasma thrusters, with SEP systems. The same payload is assumed in both cases. The task remains to find the final mass ratios and cost estimates and to determine the particular features of each technology. Each technology has its own virtues and vices: NEP implies orbiting a sizeable nuclear reactor and a power generation system capable of converting thermal into electric power, with minimum mass and volumes compatible with Ariane 5 or the Space Shuttle bay. Issues of safety and launch risks are especially important to public opinion, which is a factor to be reckoned with. Power conversion in space, including thermal cycle efficiency and radiators, is a technical issue in need of attention if power is large, i.e., of order 0.1 MW and above, and so is power conditioning and other ancillary systems. Type of mission, Isp and thrust will ultimately determine a large fraction of the mass to be orbited, as they drive propellant mass. For manned missions, the trade-off also involves consumables and travel time because of exposure to Solar wind and cosmic radiation. Future manned NEP missions will probably need superconducting coils, entailing cryostat technology. The on-board presence of cryogenic propellant (e.g., LH2) may reassure the feasibility of this technology, implying, however, a trade-off between propellant volume to be orbited and reduced thruster mass. SEP is attractive right now in the mind of the public, but also of scientists involved in Solar system exploration. Some of the appeal derives from the hope of reducing propellant mass because of the perceived high Isp of ion engines or future MPD. The comparison, in fact, will show whether the two systems could have the same type of thruster or not, for automatic or for manned missions. The main drawback of SEP is due to photovoltaics and the total solar cell area required, driving spacecraft mass and orbiting costs up. In addition, the question of using superconducting coils holds also for SEP, while no space radiator is, in principle, needed. These and other factors will be considered in this comparison. The goal is to provide preliminary guidelines in evaluating SEP and NEP that may be useful to suggest closer scrutiny of promising concepts, or even potential solutions. [copyright] 2004 American Institute of Physics

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Electric Propulsion; Ion Engines; Mars Missions; Nuclear Electric Propulsion; Nuclear Propulsion; Propulsion; Propulsion System Configurations; Propulsion System Performance; Radiation Pressure; Solar Electric Propulsion; Spacecraft

20040020165

ENABLER Nuclear Propulsion System Conceptual Design

Pauley, Keith A.; Woodham, Kurt; Ohi, Don; Haga, Heath; Henderson, Bo; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 277-284; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright

The Titan Corporation conducted a systems engineering study to develop an overall architecture that meets both the articulated and unarticulated requirements on the Prometheus Program with the least development effort. Key elements of the Titan-designed ENABLER system include a thermal fission reactor, thermionic power converters, sodium heat pipes, ion thruster engines, and a radiation shield and deployable truss to protect the payload. The overall design is scaleable over a wide range of power requirements from 10s of kilowatts to 10s of megawatts. [copyright] 2004 American Institute of Physics

Author (AIP)

Electric Generators; Heat Pipes; Nuclear Propulsion; Oxygen Compounds; Propulsion; Radiation Protection; Spacecraft; Spacecraft Power Supplies; Stress Analysis; Systems Engineering; Thermoelectric Generators; Uranium Compounds

20040020153

Market Driven Space Exploration

Gavert, Raymond B.; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 183-188; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright

Market driven space exploration will have the opportunity to develop to new levels with the coming of space nuclear power and propulsion. NASA's recently established Prometheus program is expected to receive several billion dollars over the next five years for developing nuclear power and propulsion systems for future spacecraft. Not only is nuclear power and propulsion essential for long distance Jupiter type missions, but it also important for providing greater access to planets and bodies nearer to the Earth. NASA has been working with industrial partners since 1987 through its Research Partnerships Centers (RPCs) to utilize the attributes of space in Low Earth Orbit (LEO). Plans are now being made to utilize the RPCs and industrial partners in extending the duration and boundaries of human space flight to create new opportunities for exploration and discovery. Private investors are considering setting up shops in LEO for commercial purposes. The trend is for more industrial involvement in space. Nuclear power and propulsion will hasten the progress. The objective of this paper is to show the progression of space market driven research and its potential for supporting space exploration given nuclear power and propulsion capabilities. [copyright] 2004 American Institute of Physics

Author (AIP)

Budgeting; Electric Generators; Marketing; Nuclear Propulsion; Propulsion; Research and Development; Research Management; Space Exploration; Spacecraft Power Supplies

20040005901 NASA Glenn Research Center, Cleveland, OH, USA

High Power MPD Nuclear Electric Propulsion (NEP) for Artificial Gravity HOPE Missions to Callisto

McGuire, Melissa L.; Borowski, Stanley K.; Mason, Lee M.; Gilland, James; December 2003; In English, 2-6 Feb. 2003, Albuquerque, NM, USA

Contract(s)/Grant(s): WBS 22-706-87-02

Report No.(s): NASA/TM-2003-212349; E-13937; No Copyright; Avail: CASI; A03, Hardcopy

This documents the results of a one-year multi-center NASA study on the prospect of sending humans to Jupiter's moon, Callisto, using an all Nuclear Electric Propulsion (NEP) space transportation system architecture with magnetoplasmadynamic (MPD) thrusters. The fission reactor system utilizes high temperature uranium dioxide (UO2) in tungsten (W) metal matrix cermet fuel and electricity is generated using advanced dynamic Brayton power conversion technology. The mission timeframe assumes on-going human Moon and Mars missions and existing space infrastructure to support launch of cargo and crewed spacecraft to Jupiter in 2041 and 2045, respectively.

Author

Nuclear Electric Propulsion; Artificial Gravity; Callisto; Magnetoplasmadynamic Thrusters; NASA Space Programs; Space Transportation System; Manned Space Flight

20040000969 Wisconsin Univ., Madison, WI, USA
Simulation, Model Verification and Controls Development of Brayton Cycle PM Alternator: Testing and Simulation of 2 KW PM Generator with Diode Bridge Output
Stankovic, Ana V.; NASA-OAI Collaborative Aerospace Research and Fellowship Program at NASA Glenn Research Center at Lewis Field; [2003], 37-38; In English
Contract(s)/Grant(s): NCC3-979; No Copyright; Avail: CASI; A01, Hardcopy

Professor Stankovic will be developing and refining Simulink based models of the PM alternator and comparing the simulation results with experimental measurements taken from the unit. Her first task is to validate the models using the experimental data. Her next task is to develop alternative control techniques for the application of the Brayton Cycle PM Alternator in a nuclear electric propulsion vehicle. The control techniques will be first simulated using the validated models then tried experimentally with hardware available at NASA. Testing and simulation of a 2KW PM synchronous generator with diode bridge output is described. The parameters of a synchronous PM generator have been measured and used in simulation. Test procedures have been developed to verify the PM generator model with diode bridge output. Experimental and simulation results are in excellent agreement.
Author
Electric Generators; Brayton Cycle; Control Systems Design; Simulation

20040000499 NASA Marshall Space Flight Center, Huntsville, AL, USA
Space Environments and Effects (SEE) Program: Spacecraft Charging Technology Development Activities
Kauffman, B.; Hardage, D.; Minor, J.; October 07, 2003; In English, 20-24 Oct. 2003, Huntsville, AL, USA; No Copyright; Avail: CASI; A03, Hardcopy

Reducing size and weight of spacecraft, along with demanding increased performance capabilities, introduces many uncertainties in the engineering design community on how materials and spacecraft systems will perform in space. The engineering design community is forever behind on obtaining and developing new tools and guidelines to mitigate the harmful effects of the space environment. Adding to this complexity is the continued push to use Commercial-off-the-shelf (COTS) microelectronics, potential usage of unproven technologies such as large solar sail structures and nuclear electric propulsion. In order to drive down these uncertainties, various programs are working together to avoid duplication, save what resources are available in this technical area and possess a focused agenda to insert these new developments into future mission designs. This paper will introduce the SEE Program, briefly discuss past and currently sponsored spacecraft charging activities and possible future endeavors.
Author
Aerospace Environments; Weight Reduction; Spacecraft Charging; Commercial Off-the-Shelf Products; Microelectronics; Nuclear Electric Propulsion

20030112443 NASA Marshall Space Flight Center, Huntsville, AL, USA
Using a Genetic Algorithm to Design Nuclear Electric Spacecraft
Pannell, William P.; October 27, 2003; In English, 30-31 Oct. 2003, Huntsville, AL, USA; No Copyright; Avail: CASI; A02, Hardcopy

The basic approach to to design nuclear electric spacecraft is to generate a group of candidate designs, see how 'fit' the design are, and carry best design forward to the next generation. Some designs eliminated, some randomly modified and carried forward.
Derived from text
Genetic Algorithms; Computer Programs; Nuclear Electric Propulsion

20030111795 NASA Marshall Space Flight Center, Huntsville, AL, USA
Propulsion Research at the Propulsion Research Center of the NASA Marshall Space Flight Center
Blevins, John; Rodgers, Stephen; [2003]; In English, 29 Sep. - 3 Oct. 2003, Bremen, Germany; No Copyright; Avail: Other Sources; Abstract Only

The Propulsion Research Center of the NASA Marshall Space Flight Center is engaged in research activities aimed at providing the bases for fundamental advancement of a range of space propulsion technologies. There are four broad research themes. Advanced chemical propulsion studies focus on the detailed chemistry and transport processes for high-pressure combustion, and on the understanding and control of combustion stability. New high-energy propellant research ranges from theoretical prediction of new propellant properties through experimental characterization propellant performance, material

interactions, aging properties, and ignition behavior. Another research area involves advanced nuclear electric propulsion with new robust and lightweight materials and with designs for advanced fuels. Nuclear electric propulsion systems are characterized using simulated nuclear systems, where the non-nuclear power source has the form and power input of a nuclear reactor. This permits detailed testing of nuclear propulsion systems in a non-nuclear environment. In-space propulsion research is focused primarily on high power plasma thruster work. New methods for achieving higher thrust in these devices are being studied theoretically and experimentally. Solar thermal propulsion research is also underway for in-space applications. The fourth of these research areas is advanced energetics. Specific research here includes the containment of ion clouds for extended periods. This is aimed at proving the concept of antimatter trapping and storage for use ultimately in propulsion applications. Another activity in this involves research into lightweight magnetic technology for space propulsion applications.
Author
Propulsion System Configurations; Propellant Properties; Propulsion System Performance; Aerospace Engineering; Combustion Stability; Nuclear Electric Propulsion

20030111787 NASA Marshall Space Flight Center, Huntsville, AL, USA
Space Environments and Effects (SEE) Program: Spacecraft Charging Technology Development Activities
Kauffman, Billy; Hardage, Donna; Minor, Jody; October 07, 2003; In English, 20-24 Oct. 2003, Huntsville, AL, USA; No Copyright; Avail: CASI; A02, Hardcopy

Reducing size and weight of spacecraft, along with demanding increased performance capabilities, introduces many uncertainties in the engineering design community on how materials and spacecraft systems will perform in space. The engineering design community is forever behind on obtaining and developing new tools and guidelines to mitigate the harmful effects of the space environment. Adding to this complexity is the continued push to use Commercial-off-the-shelf (COTS) microelectronics, potential usage of unproven technologies such as large solar sail structures and nuclear electric propulsion. In order to drive down these uncertainties, various programs are working together to avoid duplication, save what resources are available in this technical area and possess a focused agenda to insert these new developments into future mission designs. This paper will introduce the SEE Program, briefly discuss past and currently sponsored spacecraft charging activities and possible future endeavors.
Author
Spacecraft Charging; Nuclear Electric Propulsion; Aerospace Environments; Microelectronics

20030111762 NASA Marshall Space Flight Center, Huntsville, AL, USA
Nuclear Electric Propulsion for Outer Space Missions
Barret, Chris; [2003]; In English, 9-11 Oct. 2003, Birmingham, AL, USA; No Copyright; Avail: Other Sources; Abstract Only

Today we know of 66 moons in our very own Solar System, and many of these have atmospheres and oceans. In addition, the Hubble (optical) Space Telescope has helped us to discover a total of 100 extra-solar planets, i.e., planets going around other suns, including several solar systems. The Chandra (X-ray) Space Telescope has helped us to discover 33 Black Holes. There are some extremely fascinating things out there in our Universe to explore. In order to travel greater distances into our Universe, and to reach planetary bodies in our Solar System in much less time, new and innovative space propulsion systems must be developed. To this end NASA has created the Prometheus Program. When one considers space missions to the outer edges of our Solar System and far beyond, our Sun cannot be relied on to produce the required spacecraft (s/c) power. Solar energy diminishes as the square of the distance from the Sun. At Mars it is only 43% of that at Earth. At Jupiter, it falls off to only 3.6% of Earth's. By the time we get out to Pluto, solar energy is only .066% what it is on Earth. Therefore, beyond the orbit of Mars, it is not practical to depend on solar power for a s/c. However, the farther out we go the more power we need to heat the s/c and to transmit data back to Earth over the long distances. On Earth, knowledge is power. In the outer Solar System, power is knowledge. It is important that the public be made aware of the tremendous space benefits offered by Nuclear Electric Propulsion (NEP) and the minimal risk it poses to our environment. This paper presents an overview of the reasons for NEP systems, along with their basic components including the reactor, power conversion units (both static and dynamic), electric thrusters, and the launch safety of the NEP system.
Author
Nuclear Electric Propulsion; Space Missions; Interplanetary Flight; Interstellar Travel; NASA Programs

20030105581 NASA Glenn Research Center, Cleveland, OH, USA
A Power Conversion Concept for the Jupiter Icy Moons Orbiter
Mason, Lee S.; September 2003; In English, 17-21 Aug. 2003, Portsmouth, VA, USA
Contract(s)/Grant(s): WBS 22-973-90-01
Report No.(s): NASA/TM-2003-212596; E-14153; NAS 1.15:212596; AIAA Paper 2003-6007; No Copyright; Avail: CASI; A03, Hardcopy

The Jupiter Icy Moons Orbiter (JIMO) mission is currently under study by the Office of Space Science under the Project Prometheus Program. JIMO is examining the use of Nuclear Electric Propulsion (NEP) to carry scientific payloads to three Jovian moons. A potential power system concept includes dual 100 kWe Brayton converters, a deployable pumped loop heat rejection subsystem, and a 400 Vac Power Management and Distribution (PMAD) bus. Many trades were performed in aniving at this candidate power system concept. System-level studies examined design and off-design operating modes, determined startup requirements, evaluated subsystem redundancy options, and quantified the mass and radiator area of reactor power systems from 20 to 200 kWe. In the Brayton converter subsystem, studies were performed to investigate converter packaging options, and assess the induced torque effects on spacecraft dynamics due to rotating machinery. In the heat rejection subsystem, design trades were conducted on heat transport approaches, material and fluid options, and deployed radiator geometries. In the PMAD subsystem, the overall electrical architecture was defined and trade studies examined distribution approaches, voltage levels, and cabling options.
Author
Nuclear Electric Propulsion; Electric Power; Jupiter Satellites; NASA Space Programs; Spacecraft Maneuvers

20030080864
Saturn ring observer
Spilker, Thomas R.; Acta Astronautica; January/March 2003; ISSN 0094-5765; Volume 52, Issue no. 2-6, p. 259-265; In English; Copyright; Avail: Other Sources

Scientists studying planetary ring systems and planetary system formation have long wanted close-up (a few km) observations of Saturn's rings to answer fundamental questions about ring particle characteristics and behavior. But missions to implement these observations involve post-approach Delta V requirements greater than 10 km/s, so past designs have called upon Nuclear Electric Propulsion - an untenable position in the current programmatic climate. A unique new mission design uses carefully designed aerocapture to decrease the Delta V requirement to as little as 3.5 km/s, a difficult but not impossible feat for high-performance chemical propulsion systems. Propulsion costs dominate cost estimates for the Saturn Ring Observer mission. Driving down propulsion costs is an important facet of the strategic technology program, one that would provide cost benefits to many other missions. (copyright) 2002 Published by Elsevier Science Ltd.
EI
Aerospace Sciences; Nuclear Propulsion; Particle Size Distribution; Planets; Spacecraft

20030067740 NASA Marshall Space Flight Center, Huntsville, AL, USA
The Case of Nuclear Propulsion
Koroteev, Anatoly S.; Ponomarev-Stepnoi, Nicolai N.; Smetannikov, Vladimir P.; Gafarov, Albert A.; Houts, Mike; VanDyke, Melissa; Godfroy, Tom; Martin, James; Bragg-Sitton, Shannon; Dickens, Ricky, et al.; [2003]; In English, 13-17 Jul. 2003, Dayton, OH, USA; Copyright; Avail: CASI; A02, Hardcopy

Fission technology can enable rapid, affordable access to any point in the solar system. If fission propulsion systems are to be developed to their full potential; however, near-term customers must be identified and initial fission systems successfully developed, launched, and utilized. Successful utilization will simultaneously develop the infrastructure and experience necessary for developing even higher power and performance systems. To be successful, development programs must devise strategies for rapidly converting paper reactor concepts into actual flight hardware. One approach to accomplishing this is to design highly testable systems, and to structure the program to contain frequent, significant hardware milestones. This paper discusses ongoing efforts in Russia and the USA aimed at enabling near-term utilization of space fission systems.
Author
Nuclear Electric Propulsion; Propulsion System Configurations; Aerospace Systems; Nuclear Rocket Engines; NASA Space Programs

20030067417 NASA Marshall Space Flight Center, Huntsville, AL, USA

High-Energy Two-Stage Pulsed Plasma Thruster

Markusic, Tom; [2003]; In English, 20-23 Jul. 2003, Huntsville, AL, USA; No Copyright; Avail: Other Sources; Abstract Only

A high-energy (28 kJ per pulse) two-stage pulsed plasma thruster (MSFC PPT-1) has been constructed and tested. The motivation of this project is to develop a high power (approximately 500 kW), high specific impulse (approximately 10000 s), highly efficient (greater than 50%) thruster for use as primary propulsion in a high power nuclear electric propulsion system. PPT-1 was designed to overcome four negative characteristics which have detracted from the utility of pulsed plasma thrusters: poor electrical efficiency, poor propellant utilization efficiency, electrode erosion, and reliability issues associated with the use of high speed gas valves and high current switches. Traditional PPTs have been plagued with poor efficiency because they have not been operated in a plasma regime that fully exploits the potential benefits of pulsed plasma acceleration by electromagnetic forces. PPTs have generally been used to accelerate low-density plasmas with long current pulses. Operation of thrusters in this plasma regime allows for the development of certain undesirable particle-kinetic effects, such as Hall effect-induced current sheet canting. PPT-1 was designed to propel a highly collisional, dense plasma that has more fluid-like properties and, hence, is more effectively pushed by a magnetic field. The high-density plasma loading into the second stage of the accelerator is achieved through the use of a dense plasma injector (first stage). The injector produces a thermal plasma, derived from a molten lithium propellant feed system, which is subsequently accelerated by the second stage using mega-amp level currents, which eject the plasma at a speed on the order of 100 kilometers per second. Traditional PPTs also suffer from dynamic efficiency losses associated with snowplow loading of distributed neutral propellant. The twostage scheme used in PPT-I allows the propellant to be loaded in a manner which more closely approximates the optimal slug loading. Lithium propellant was chosen to test whether or not the reduced electrode erosion found in the Lithium Lorentz Force Accelerator (LiLFA) could also be realized in a pulsed plasma thruster. The use of the molten lithium dense plasma injector also eliminates the need for a gas valve and electrical switch; the injector design fulfills both roles, and uses no moving parts to provide, in principle, a highly reliable propellant feed and electrical switching system. Experimental results reported in this paper include: second-stage current traces, high-speed photographic and holographic imaging of the thruster exit plume, and internal mapping of the discharge chamber magnetic field from B-dot probe data. The magnetic field data is used to create a two-dimensional description of the evolution of the current sheet inside the thruster.

Author

High Speed; Magnetic Fields; Plasma Acceleration; Plasmas (Physics); Pulsed Plasma Thrusters; Nuclear Electric Propulsion

20030066527 NASA Marshall Space Flight Center, Huntsville, AL, USA

Cycle Trades for Nuclear Thermal Rocket Propulsion Systems

White, C.; Guidos, M.; Greene, W.; [2003]; In English, 20-23 Jul. 2003, Huntsville, AL, USA

Report No.(s): AIAA Paper 2003-5131; No Copyright; Avail: CASI; A02, Hardcopy

Nuclear fission has been used as a reliable source for utility power in the USA for decades. Even in the 1940's, long before the USA had a viable space program, the theoretical benefits of nuclear power as applied to space travel were being explored. These benefits include long-life operation and high performance, particularly in the form of vehicle power density, enabling longer-lasting space missions. The configurations for nuclear rocket systems and chemical rocket systems are similar except that a nuclear rocket utilizes a fission reactor as its heat source. This thermal energy can be utilized directly to heat propellants that are then accelerated through a nozzle to generate thrust or it can be used as part of an electricity generation system. The former approach is Nuclear Thermal Propulsion (NTP) and the latter is Nuclear Electric Propulsion (NEP), which is then used to power thruster technologies such as ion thrusters. This paper will explore a number of indirect-NTP engine cycle configurations using assumed performance constraints and requirements, discuss the advantages and disadvantages of each cycle configuration, and present preliminary performance and size results. This paper is intended to lay the groundwork for future efforts in the development of a practical NTP system or a combined NTP/NEP hybrid system.

Author

Nuclear Fission; Thermal Energy; Rocket Engines; Nuclear Electric Propulsion; Heat Sources

20030066115 NASA Marshall Space Flight Center, Huntsville, AL, USA

Earth-to-Orbit Rocket Propulsion

Beaurain, Andre; Souchier, Alain; Moravie, Michel; Sackheim, Robert L.; Cikanek, Harry A., III; March 31, 2003; In English, 14-18 Jul. 2003, Dayton, OH, USA; Copyright; Avail: CASI; A03, Hardcopy

The Earth-to-orbit (ETO) phase of access to space is and always will be the first and most critical phase of all space missions. This first phase of all space missions has unique characteristics that have driven space launcher propulsion

requirements for more than half a century. For example, the need to overcome the force of the Earth s gravity in combination with high levels of atmospheric drag to achieve the initial orbital velocity; i.e., Earth parking orbit or =9 km/s, will always require high thrust- to-weight (TN) propulsion systems. These are necessary with a T/W ratio greater than one during the ascent phase. The only type of propulsion system that can achieve these high T/W ratios are those that convert thermal energy to kinetic energy. There are only two basic sources of onboard thermal energy: chemical combustion-based systems or nuclear thermal-based systems (fission, fusion, or antimatter). The likelihood of advanced open-cycle, nuclear thermal propulsion being developed for flight readiness or becoming environmentally acceptable during the next century is extremely low. This realization establishes that chemical propulsion for ET0 launchers will be the technology of choice for at least the next century, just as it has been for the last half century of rocket flight into space. The world s space transportation propulsion requirements have evolved through several phases over the history of the space program, as has been necessitated by missions and systems development, technological capabilities available, and the growth and evolution of the utilization of space for economic, security, and science benefit. Current projections for the continuing evolution of requirements and concepts may show how future space transportation system needs could be addressed. The evolution and projections will be described in detail in this manuscript.
Author
Earth Orbits; Reusable Rocket Engines; Reusable Spacecraft; Reusable Launch Vehicles

20030066010 NASA Marshall Space Flight Center, Huntsville, AL, USA
Marshall Space Flight Center and the Reactor-in-Flight Stage: A Look Back at Using Nuclear Propulsion to Power Space Vehicles in the 1960's
Wright, Mike; [2003]; In English, 20-23 Jul. 2003, Huntsville, AL, USA
Report No.(s): AIAA Paper 2003-4588; No Copyright; Avail: CASI; A01, Hardcopy

This paper examines the Marshall Space Flight Center s role in the Reactor-In-Flight (RIlT) project that NASA was involved with in the early 1960 s. The paper outlines the project s relation to the joint NASA-Atomic Energy Commission nuclear initiative known as Project Rover. It describes the justification for the RIFT project, its scope, and the difficulties that were encountered during the project. It also provides as assessment of NASA s overall capabilities related to nuclear propulsion in the early 1960 s.
Author
Nuclear Propulsion; Rover Project

20030065959 NASA Marshall Space Flight Center, Huntsville, AL, USA
Technology Development Activities for the Space Environment and its Effects on Spacecraft
Kauffman, Billy; Hardage, Donna; Minor, Jody; Barth, Janet; LaBel, Ken; March 31, 2003; In English, 14-18 Jul. 2003, Dayton, OH, USA; No Copyright; Avail: CASI; A02, Hardcopy

Reducing size and weight of spacecraft, along with demanding increased performance capabilities, introduces many uncertainties in the engineering design community on how emerging microelectronics will perform in space. The engineering design community is forever behind on obtaining and developing new tools and guidelines to mitigate the harmful effects of the space environment. Adding to this complexity is the push to use Commercial-off-the-shelf (COTS) and shrinking microelectronics behind less shielding and the potential usage of unproven technologies such as large solar sail structures and nuclear electric propulsion. In order to drive down these uncertainties, various programs are working together to avoid duplication, save what resources are available in this technical area and possess a focused agenda to insert these new developments into future mission designs. This paper will describe the relationship between the Living With a Star (LWS): Space Environment Testbeds (SET) Project and NASA's Space Environments and Effects (SEE) Program and their technology development activities funded as a result from the recent SEE Program's NASA Research Announcement.
Author
Aerospace Environments; NASA Programs; Research and Development

20030065898 Boeing Phantom Works, Huntsville, AL, USA
High Power Electric Propulsion for Outer Planet Missions
Donahue, Benjamin B.; [2003]; In English, 23 Jul. 2003, Huntsville, AL, USA
Contract(s)/Grant(s): GS-234-01075; Copyright; Avail: CASI; A02, Hardcopy

Focused technology trade studies for Nuclear Electric Propulsion vehicle concepts for outer planet missions are presented; representative mission, vehicle and technology characterizations illustrate samples of work done under the NASA Marshall

Space Flight Center-Boeing-SAIC In-Space Technology Assessment (ISTA) contract. An objective of ISTA is to identify and present sound technical and programtic options for the formulation and implementation of advanced electric and chemical propulsion solar system exploration missions. Investigations to date include a variety of outer planet destinations, trip times, science payload allotments, orbital capture techniques, all conducted to illustrate how advanced technology would maximize mission benefits. Architecture wide optimizations that facilitate good propulsion technology investments for advanced electric and chemical propulsion systems were conducted, including those relevant to the nuclear system initiative. Representative analyses of vehicles utilizing fission reactors with advanced power generation, Conversion, processing and electric propulsion systems, which would enable scientifically rich robotic exploration missions, are presented.
Author
Interplanetary Spacecraft; Space Exploration; Nuclear Electric Propulsion; Propulsion System Configurations; Technology Assessment

20030065315 NASA Marshall Space Flight Center, Huntsville, AL, USA
Design Development Analyses in Support of a Heatpipe-Brayton Cycle Heat Exchanger
Steeve, Brian; VanDyke, Melissa; Majumdar, Alok; Nguyen, Dalton; Corley, Melissa; Guffee, Ray M.; Kapernick, Richard J.; [2003]; In English; Space Technology and Applications International Forum, 2-5 Feb. 2003, Albuquerque, NM, USA; Copyright; Avail: Other Sources

One of the power systems under consideration for nuclear electric propulsion or as a planetary surface power source is a heatpipe-cooled reactor coupled to a Brayton cycle. In this system, power is transferred from the heatpipes to the Brayton gas via a heat exchanger attached to the heatpipes. This paper discusses the fluid, thermal and structural analyses that were performed in support of the design of the heat exchanger to be tested in the SAFE-100 experimental program at Marshall Space Flight Center. A companion paper, 'Mechanical Design and Fabrication of a SAFE-100 Heat Exchanger for use in NASA s Advanced Propulsion Thermal-hydraulic Simulator', presents the fabrication issues and prototyping studies that, together with these analyses, led to the development of this heat exchanger. An important consideration throughout the design development of the heat exchanger was its capability to be utilized for higher power and temperature applications. This paper also discusses this aspect of the design and presents designs for specific applications that are under consideration.
Author
Heat Exchangers; Brayton Cycle; Design Analysis; Nuclear Electric Propulsion; Structural Analysis

20030062199 NASA Marshall Space Flight Center, Huntsville, AL, USA
Thermally Simulated Testing of a Direct-Drive Gas-Cooled Nuclear Reactor
Godfroy, Thomas; Bragg-Sitton, Shannon; VanDyke, Melissa; [2003]; In English, 4-7 May 2003, Cordoba, Spain; No Copyright; Avail: CASI; A02, Hardcopy

This paper describes the concept and preliminary component testing of a gas-cooled, UN-fueled, pin-type reactor which uses He/Xe gas that goes directly into a recuperated Brayton system to produce electricity for nuclear electric propulsion. This Direct-Drive Gas-Cooled Reactor (DDG) is designed to be subcritical under water or wet-sand immersion in case of a launch accident. Because the gas-cooled reactor can directly drive the Brayton turbomachinery, it is possible to configure the system such that there are no external surfaces or pressure boundaries that are refractory metal, even though the gas delivered to the turbine is 1144 K. The He/Xe gas mixture is a good heat transport medium when flowing, and a good insulator when stagnant. Judicious use of stagnant cavities as insulating regions allows transport of the 1144-K gas while keeping all external surfaces below 900 K. At this temperature super-alloys (Hastelloy or Inconel) can be used instead of refractory metals. Super-alloys reduce the technology risk because they are easier to fabricate than refractory metals, we have a much more extensive knowledge base on their characteristics, and, because they have a greater resistance to oxidation, system testing is eased. The system is also relatively simple in its design: no additional coolant pumps, heat exchanger, or freeze-thaw systems are required. Key to success of this concept is a good knowledge of the heat transfer between the fuel pins and the gas, as well as the pressure drop through the system. This paper describes preliminary testing to obtain this key information, as well as experience in demonstrating electrical thermal simulation of reactor components and concepts.
Author
Gas Cooled Reactors; Brayton Cycle; Gas Turbine Engines; Nuclear Electric Propulsion; Turbomachinery; Structural Design; Heat Transfer; Systems Engineering

20030062058 NASA Marshall Space Flight Center, Huntsville, AL, USA
Antimatter Driven P-B11 Fusion Propulsion System
Kammash, Terry; Martin, James; Godfroy, Thomas; [2002]; In English, 2-6 Feb. 2003, Albuquerque, NM, USA; Copyright; Avail: CASI; A02, Hardcopy

One of the major advantages of using P-B11 fusion fuel is that the reaction produces only charged particles in the form of three alpha particles and no neutrons. A fusion concept that lends itself to this fuel cycle is the Magnetically Insulated Inertial Confinement Fusion (MICF) reactor whose distinct advantage lies in the very strong magnetic field that is created when an incident particle (or laser) beam strikes the inner wall of the target pellet. This field serves to thermally insulate the hot plasma from the metal wall thereby allowing thc plasma to burn for a long time and produce a large energy magnification. If used as a propulsion device, we propose using antiprotons to drive the system which we show to be capable of producing very large specific impulse and thrust. By way of validating the confinement propenies of MICF we will address a proposed experiment in which pellets coated with P-B11 fuel at the appropriate ratio will be zapped by a beam of antiprotons that enter the target through a hole. Calculations showing the density and temperature of the generated plasma along with the strength of the magnetic field and other properties of the system will be presented and discussed.
Author
Matter-Antimatter Propulsion; Nuclear Propulsion; Spacecraft Propulsion; Antiprotons; Particle Beams; Propellants

20030062031 NASA Marshall Space Flight Center, Huntsville, AL, USA
Overview of NASA's Space Environments and Effects (SEE) Program Technology Development Activities
Kauffman, Billy; Hardage, Donna; Minor, Jody; March 25, 2003; In English, Mar. 2003, Rhodes, Greece; No Copyright; Avail: Other Sources; Abstract Only

Reducing size and weight of spacecraft, along with demanding increased performance capabilities, introduces many uncertainties in the engineering design community on how spacecraft and spacecraft systems will perform in space. The engineering design community is forever behind on obtaining and developing new tools and guidelines to mitigate the harmful effects of the space environment. Adding to this complexity is the push to use Commercial-off-the-shelf (COTS) and shrinking microelectronics behind less shielding utilizing new materials. The potential usage of unproven technologies such as large solar sail structures and nuclear electric propulsion introduces new requirements to develop new engineering tools. In order to drive down these uncertainties, NASA s SEE Program provides resources for technology development to accommodate or mitigate these harmful environments on spacecraft. This paper will describe the current SEE Program's, currently funded activities and possible future developments.
Author
Aerospace Environments; Commercial Off-the-Shelf Products; Spacecraft Design; Spacecraft Performance; Weight Reduction; Microelectronics

20030061234 NASA Marshall Space Flight Center, Huntsville, AL, USA
Test Facilities in Support of High Power Electric Propulsion Systems
VanDyke, Melissa; Houts, Mike; Godfroy, Thomas; Dickens, Ricky; Martin, James J.; Salvail, Patrick; Carter, Robert; [2002]; In English; STAIF 2003, 2-6 Feb. 2003, Albuquerque, NM, USA; No Copyright; Avail: CASI; A02, Hardcopy

Successful development of space fission systems requires an extensive program of affordable and realistic testing. In addition to tests related to design/development of the fission system, realistic testing of the actual flight unit must also be performed. If the system is designed to operate within established radiation damage and fuel burn up limits while simultaneously being designed to allow close simulation of heat from fission using resistance heaters, high confidence in fission system performance and lifetime can be attained through non-nuclear testing. Through demonstration of systems concepts (designed by DOE National Laboratories) in relevant environments, this philosophy has been demonstrated through hardware testing in the High Power Propulsion Thermal Simulator (HPPTS). The HPPTS is designed to enable very realistic non-nuclear testing of space fission systems. Ongoing research at the HPPTS is geared towards facilitating research, development, system integration, and system utilization via cooperative efforts with DOE labs, industry, universities, and other NASA centers. Through hardware based design and testing, the HPPTS investigates High Power Electric Propulsion (HPEP) component, subsystem, and integrated system design and performance.
Author
Test Facilities; Fission; Spacecraft Propulsion; Systems Simulation; Nuclear Electric Propulsion; Performance Tests

20030061231 NASA Marshall Space Flight Center, Huntsville, AL, USA
Direct-Drive Gas-Cooled Reactor Power System: Concept and Preliminary Testing
Wright, S. A.; Lipinski, R. J.; Godfroy, T. J.; Bragg-Sitton, S. M.; VanDyke, M. K.; [2002]; In English, 2-6 Feb. 2003, Albuquerque, NM, USA; No Copyright; Avail: CASI; A02, Hardcopy

This paper describes the concept and preliminary component testing of a gas-cooled, UN-fueled, pin-type reactor which

uses He/Xe gas that goes directly into a recuperated Brayton system to produce electricity for nuclear electric propulsion. This Direct-Drive Gas-Cooled Reactor (DDG) is designed to be subcritical under water or wet- sand immersion in case of a launch accident. Because the gas-cooled reactor can directly drive the Brayton turbomachinery, it is possible to configure the system such that there are no external surfaces or pressure boundaries that are refractory metal, even though the gas delivered to the turbine is 1144 K. The He/Xe gas mixture is a good heat transport medium when flowing, and a good insulator when stagnant. Judicious use of stagnant cavities as insulating regions allows transport of the 1144-K gas while keeping all external surfaces below 900 K. At this temperature super-alloys (Hastelloy or Inconel) can be used instead of refractory metals. Super-alloys reduce the technology risk because they are easier to fabricate than refractory metals, we have a much more extensive knowledge base on their characteristics, and, because they have a greater resistance to oxidation, system testing is eased. The system is also relatively simple in its design: no additional coolant pumps, heat exchanger, or freeze-thaw systems are required. Key to success of this concept is a good knowledge of the heat transfer between the fuel pins and the gas, as well as the pressure drop through the system. This paper describes preliminary testing to obtain this key information, as well as experience in demonstrating electrically heated testing of simulated reactor components.
Author
Gas Cooled Reactors; Fabrication; Systems Engineering; Gas Mixtures; Heat Resistant Alloys; Power Efficiency; Performance Tests

20030061215 NASA Marshall Space Flight Center, Huntsville, AL, USA
Hardware Based Technology Assessment in Support of Near-Term Space Fission Missions
Houts, Mike; VanDyke, Melissa; Godfroy, Tom; Martin, James; BraggSitton, Shannon; Carter, Robert; Dickens, Ricky; Salvail, Pat; Williams, Eric; Harper, Roger, et al.; [2003]; In English, 2-6 Feb. 2003, Albuquerque, NM, USA; Copyright; Avail: CASI; A02, Hardcopy

Fission technology can enable rapid, affordable access to any point in the solar system. If fission propulsion systems are to be developed to their full potential; however, near-term customers must be identified and initial fission systems successfully developed, launched, and utilized. Successful utilization will most likely occur if frequent, significant hardware-based milestones can be achieved throughout the program. Achieving these milestones will depend on the capability to perform highly realistic non-nuclear testing of nuclear systems. This paper discusses ongoing and potential research that could help achieve these milestones.
Author
Fission; Space Missions; Technology Assessment; Hardware; Nuclear Electric Propulsion

20030051675
Vehicle And System Concepts For Laser Orbital Maneuvering And Interplanetary Propulsion
Kare, Jordin T.; AIP Conference Proceedings; May 14, 2003; ISSN 0094-243X; Volume 664, Issue no. 1, 662-673; In English, 5-7 November 2002, Huntsville, Alabama, USA; Copyright

In-space laser ablative propulsion using beamed power (as opposed to on-board lasers) may be superior to all alternatives, except possibly nuclear propulsion, for rapid, efficient transport within the Earth-Moon system and, eventually, the inner Solar system. The keys to this concept are large, lightweight transmitting optics and even larger, lighter vehicle-based collectors. We present scaling relationships for cislunar and interplanetary laser propulsion, and discuss some options for these components. In particular, large (10 - 50 meter) diffractive optics and holographic concentrators appear to be enabling technologies that can be demonstrated within a few years and deployed operationally in the 2010’s. [copyright] 2003 American Institute of Physics
Author (AIP)
Earth-Moon System; Electric Propulsion; Interplanetary Spacecraft; Laser Ablation; Laser Applications; Laser Beams; Laser Propulsion; Lasers; Light Transmission; Nuclear Propulsion; Orbital Maneuvers; Plasmas (Physics); Power Beaming; Rocket Engines; Solar System; Spacecraft; Spacecraft Propulsion

20030046926
Preliminary study of impact of fuel options on performance of Nuclear Thermal Propulsion (NTP) concepts
Ludewig, H.; Todosow, M.; Montanez, P.; Bezler, P.; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 1084-1095; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA; Copyright

A study of the sensitivity to fuel type and composition on the performance of two Nuclear Thermal Rocket (NTR) concepts is presented. The performance measures are the specific impulse and the thrust/weight (T/W) ratio, and the concepts

considered are based on the NERVA and ESCORT reactors. For the NERVA concept use of alternative fissile materials showed significant reductions in core mass which improves the values of T/W. However, launch safety considerations may be the dominant factor in selection of fissile material. The use of ternary carbide based fuels allows higher exhaust temperatures, but due to their higher density reduces T/W. The use of molybdenum based cermets, and cermets which use UN or UC(sub 2) fuel allow for significant reductions in the reactor mass, and thus an increase in T/W. However, the use of molybdenum reduces the exhaust temperature. Both these results for the NERVA and ESCORT based systems indicate the need to axially zone the core. The lower temperature but lighter material should be used in the cooler (\h2500 K) parts of the core, and the heavier, higher temperature material should be used in the outlet end of the core. In addition, the thermal response, and implied stress is estimated for the NERVA concept. [copyright] 2002 American Institute of Physics.
Author (AIP)
Cermets; Fissile Fuels; Molybdenum; Nuclear Propulsion; Nuclear Reactors; Rockets; Safety; Spacecraft Propulsion; Uranium Compounds

20030046924

Overview of materials technologies for space nuclear power and propulsion

Zinkle, S. J.; Ott, L. J.; Ingersoll, D. T.; Ellis, R. J.; Grossbeck, M. L.; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 1063-1073; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA
Contract(s)/Grant(s): AC05-00OR-22725; Copyright

A wide range of different space nuclear systems are currently being evaluated as part of the DOE Special Purpose Fission Technology program. The near-term subset of systems scheduled to be evaluated range from 50 kWe gas-, pumped liquid metal-, or liquid metal heat pipe-cooled reactors for space propulsion to 3 kWe heat pipe or pumped liquid metal systems for Mars surface power applications. The current status of the materials technologies required for the successful development of near-term space nuclear power and propulsion systems is reviewed. Materials examined in this overview include fuels (UN, UO(sub 2), UZrH), cladding and structural materials (stainless steel, superalloys, refractory alloys), neutron reflector materials (Be, BeO), and neutron shield materials (B(sub 4)C,LiH). The materials technologies issues are considerably less demanding for the 3 kWe reactor systems due to lower operating temperatures, lower fuel burnup, and lower radiation damage levels. A few reactor subcomponents in the 3 kWe reactors under evaluation are being used near or above their engineering limits, which may adversely affect the 5 to 10 year lifetime design goal. It appears that most of these issues for the 3 kWe reactor systems can be accommodated by incorporating a few engineering design changes. Design limits (temperature, burnup, stress, radiation levels) for the various materials proposed for space nuclear reactors will be summarized. For example, the temperature and stress limits for Type 316 stainless steel in the 3 kWe Na-cooled heat pipe reactor (Stirling engine) concept will be controlled by thermal creep and CO(sub 2) corrosion considerations rather than radiation damage issues. Conversely, the lower operating temperature limit for the LiH shield material will likely be defined by ionizing radiation damage (radiolysis)-induced swelling, even for the relatively low radiation doses associated with the 3 kWe reactor. [copyright] 2002 American Institute of Physics.
Author (AIP)
Aerospace Systems; Cladding; Coolants; Cooling; Fissile Fuels; Fission; Heat Pipes; Liquid Metals; Nuclear Fission; Nuclear Power Reactors; Nuclear Propulsion; Nuclear Reactors; Radiation Effects; Reactor Design; Spacecraft Propulsion

20030046904

End-to-End demonstrator of the Safe Affordable Fission Engine (SAFE) 30: Power conversion and ion engine operation

Hrbud, Ivana; Van Dyke, Melissa; Houts, Mike; Goodfellow, Keith; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 906-911; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA; Copyright

The Safe Affordable Fission Engine (SAFE) test series addresses Phase 1 Space Fission Systems issues in particular non-nuclear testing and system integration issues leading to the testing and non-nuclear demonstration of a 400-kW fully integrated flight unit. The first part of the SAFE 30 test series demonstrated operation of the simulated nuclear core and heat pipe system. Experimental data acquired in a number of different test scenarios will validate existing computational models, demonstrated system flexibility (fast start-ups, multiple start-ups/shut downs), simulate predictable failure modes and operating environments. The objective of the second part is to demonstrate an integrated propulsion system consisting of a core, conversion system and a thruster where the system converts thermal heat into jet power. This end-to-end system demonstration sets a precedent for ground testing of nuclear electric propulsion systems. The paper describes the SAFE 30

end-to-end system demonstration and its subsystems. [copyright] 2002 American Institute of Physics.
Author (AIP)
Aerospace Systems; Electric Propulsion; Engine Tests; Heat Pipes; Ion Engines; Nuclear Power Reactors; Nuclear Propulsion; Nuclear Reactors; Systems Integration

20030046897

Status of advanced carbide fuels: Past, present, and future
Anghaie, Samim; Knight, Travis; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 852-856; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA
Contract(s)/Grant(s): NAS-26314; NAG8-1251; Copyright

Solid solution, mixed uranium/refractory metal carbide fuels such as (U, Zr, Nb)C, so called ternary carbide or tri-carbide fuels have great potential for applications in next generation advanced nuclear power reactors. Because of their high melting points, high thermal conductivity, improved resistance to hot hydrogen corrosion, and good fission product retention, these advanced nuclear fuels have great potential for high performance reactors with increased safety margins. Despite these many benefits, some concerns regarding carbide fuels include compatibility issues with coolant and/or cladding materials and their endurance under the extreme conditions associated with nuclear thermal propulsion. The status of these fuels is reviewed to characterize their performance for space nuclear power applications. Results of current investigations are presented and as well as future directions of study for these advanced nuclear fuels. [copyright] 2002 American Institute of Physics.
Author (AIP)
Advanced Test Reactors; Carbon Compounds; Corrosion Resistance; Fissile Fuels; Melting Points; Metal Fuels; Metal Propellants; Nuclear Fuel Elements; Nuclear Power Reactors; Nuclear Reactors; Reactor Safety; Refractories; Refractory Metals; Solid Solutions; Spacecraft Propulsion; Thermal Conductivity; Uranium Carbides

20030046881

Manufacturing development for the SAFE 100 kW core
Carter, Robert; Roman, Jose; Salvail, Pat; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 726-731; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA; Copyright

In stark contrast to what is sometimes considered the norm in traditional manufacturing processes, engineers at the Marshall Space Flight Center (MSFC) arc in the practice of altering the standard in an effort to realize other potential methods in core manufacturing. While remaining within the bounds of the materials database, we are researching into core manufacturing techniques that may have been overlooked in the past due to funding and/or time constraints. To augment proven core fabrication capabilities we are pursuing plating processes as another possible method for core build-up and assembly. Although brazing and a proprietary HIP cycle are used for module assembly (proven track record for stability and endurance), it is prudent to pursue secondary or backup methods of module and core assembly. For this reason heat tube manufacture and module assembly by means of plating is being investigated. Potentially, the plating processes will give engineers the ability to manufacture replacement modules for any module that might fail to perform nominally, and to assemble/disassemble a complete core in much less time than would be required for the conventional Braze-HIP process. Another area of improvement in core manufacturing capabilities is the installation of a sodium and lithium liquid metal heat pipe fill machine. This, along with the ability to Electron Beam Weld heat pipe seals and wet-in the pipes in the necessary vacuum atmosphere, will eliminate the need to ship potentially hazardous components outside for processing. In addition to developing core manufacturing techniques, the SAFE manufacturing team has been evaluating the thermal heat transfer characteristics, and manufacturability of several heat exchanger design concepts. [copyright] 2002 American Institute of Physics.
Author (AIP)
Brazing; Electron Beam Welding; Heat Pipes; Liquid Metals; Manufacturing; Nuclear Power Reactors; Nuclear Propulsion; Nuclear Reactors; Seals (Stoppers)

20030046879

Potential operating orbits for fission electric propulsion systems driven by the SAFE-400
Houts, Mike; Kos, Larry; Poston, David; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 717-721; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002,

3-6 Feb 2002, Albuquerque, New Mexico, USA; Copyright

Safety must be ensured during all phases of space fission system design, development, fabrication, launch, operation, and shutdown. One potential space fission system application is fission electric propulsion (FEP), in which fission energy is converted into electricity and used to power high efficiency (Isp\g3000s) electric thrusters. For these types of systems it is important to determine which operational scenarios ensure safety while allowing maximum mission performance and flexibility. Space fission systems are essentially non-radioactive at launch, prior to extended operation at high power. Once high power operation begins, system radiological inventory steadily increases as fission products build up. For a given fission product isotope, the maximum radiological inventory is typically achieved once the system has operated for a length of time equivalent to several half-lives. After that time, the isotope decays at the same rate it is produced, and no further inventory builds in. For an FEP mission beginning in Earth orbit, altitude and orbital lifetime increase as the propulsion system operates. Two simultaneous effects of fission propulsion system operation are thus (1) increasing fission product inventory and (2) increasing orbital lifetime. Phrased differently, as fission products build up, more time is required for the fission products to naturally convert back into non-radioactive isotopes. Simultaneously, as fission products build up, orbital lifetime increases, providing more time for the fission products to naturally convert back into non-radioactive isotopes. Operational constraints required to ensure safety can thus be quantified. [copyright] 2002 American Institute of Physics.

Author (AIP)

Earth Orbits; Electric Propulsion; Fission Products; Nuclear Power Reactors; Nuclear Propulsion; Nuclear Reactors; Reactor Safety; Spacecraft Launching; Systems Engineering

20030046876

Phase 1 space fission propulsion system testing and development progress

Dyke, Melissa Van; Houts, Mike; Godfroy, Tom; Dickens, Ricky; Poston, David; Kapernick, Rick; Reid, Bob; Salvail, Pat; Ring, Peter; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 692-697; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA; Copyright

Successful development of space fission systems requires an extensive program of affordable and realistic testing. In addition to tests related to design/development of the fission system, realistic testing of the actual flight unit must also be performed. If the system is designed to operate within established radiation damage and fuel burn up limits while simultaneously being designed to allow close simulation of heat from fission using resistance heaters, high confidence in fission system performance and lifetime can be attained through a series of non-nuclear tests. The Safe Affordable Fission Engine (SAFE) test series, whose ultimate goal is the demonstration of a 300 kW flight configuration system, has demonstrated that realistic testing can be performed using non-nuclear methods. This test series, carried out in collaboration with other NASA centers, other government agencies, industry, and universities, successfully completed a testing program with a 30 kWt core. Stirling engine, and ion engine configuration. Additionally, a 100 kWt core is in fabrication and appropriate test facilities are being reconfigured. This paper describes the current SAFE non-nuclear tests, which includes test article descriptions, test results and conclusions, and future test plans. [copyright] 2002 American Institute of Physics.

Author (AIP)

Aerospace Systems; Nuclear Propulsion; Nuclear Reactors; Radiation Effects; Reactor Safety; Spacecraft Propulsion

20030046875

Old myths and new realities: A 21st century space reactor cost estimate

Lee, James H., Jr.; Clement, Steven D.; Hanrahan, Robert J.; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 686-691; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA; Copyright

This paper reports on a detailed costing by National Aeronautics and Space Administration Marshall Space Flight Center (MSFC) and Los Alamos National Laboratory (LANL) for the development of the Heatpipe Power System (HPS). This HPS is unique in that it was created in part to reduce development and deployment costs, as well as development time (another significant cost driver). These unique design features are discussed as a basis for the development cost estimate. Key assumptions are core modularity, which makes required testing easier and less costly, as well as the ability of this reactor concept to be fully designed, developed, flight tested, and deployed without the expense of a full-power ground nuclear test. Assumptions for a streamlined program management structure to keep costs at a minimum also are discussed. The various elements of the development program also are presented in summary. The development program of the HPS, to include reactor, heat pipes, shielding, instrumentation and control, reflector, and heat-pipe to gas-heat exchanges has been initially estimated by LANL and MSFC as $210-$250 million and requires 7 years to develop and test for a 400 KW (th) HPS coupled to a

Brayton conversion system. [copyright] 2002 American Institute of Physics.
Author (AIP)
Cost Estimates; Heat Pipes; Heat Transfer; Laboratory Equipment; NASA Programs; Nuclear Fission; Nuclear Power Reactors; Nuclear Propulsion; Nuclear Reactors; Project Management; Reactor Design; Shielding; Spacecraft

20030046872

Thermal stress calculations for heatpipe-cooled reactor power systems

Kapernick, Richard J.; Guffee, Ray M.; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 666-672; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA; Copyright

A heatpipe-cooled fast reactor concept has been under development at Los Alamos National Laboratory for the past several years, to be used as a power source for nuclear electric propulsion (NEP) or as a planetary surface power system. The reactor core consists of an array of modules that are held together by a core lateral restraint system. Each module comprises a single heatpipe surrounded by 3-6 clad fuel pins. As part of the design development and performance assessment activities for these reactors, specialized methods and models have been developed to perform thermal and stress analyses of the core modules. The methods have been automated so that trade studies can be readily performed, looking at design options such as module size, heatpipe and clad thickness, use of sleeves to contain the fuel, material type, etc. This paper describes the methods and models that have been developed, and presents thermal and stress analysis results for a Mars surface power system and a NEP power source. [copyright] 2002 American Institute of Physics.
Author (AIP)
Electric Propulsion; Fast Nuclear Reactors; Heat Pipes; Nuclear Electric Propulsion; Nuclear Power Reactors; Nuclear Reactors; Planetary Surfaces; Spacecraft Propulsion; Stress Analysis; Thermal Stresses

20030046869

NEP missions to Pluto

Lipinski, Ronald J.; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 645-651; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA
Contract(s)/Grant(s): AC04-94AL-85000; Copyright

Nuclear Electric Propulsion (NEP) has the potential to deliver fast trips to the distant outer planets and to be enabling for orbiter missions to Pluto, the moons of the distant outer planets, and Kuiper belt objects. This paper summarizes results of a mission study for a Pluto Flyby and a Pluto Orbiter. It was concluded that the flyby mission trip time would be about 6-10 years, depending on how lightweight the power system could be made for a given power level. The trip time was not too sensitive to whether the initial condition was earth escape or earth orbit if a larger power system could be assumed for the earth-orbit option because of the larger launch mass that could be used in that case. The trip time for the orbiter mission was projected to be about 9-14 years. [copyright] 2002 American Institute of Physics.
Author (AIP)
Earth Orbits; Electric Propulsion; Gas Giant Planets; Grand Tours; Kuiper Belt; Moon; Nuclear Electric Propulsion; Nuclear Propulsion; Nuclear Reactors; Pluto (Planet); Spacecraft; Spacecraft Propulsion

20030046866

Evaluation of high-performance space nuclear electric generators for electric propulsion application

Woodcock, Gordon; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 617-626; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA
Contract(s)/Grant(s): GSA-GS-23F-0107J; Copyright

Electric propulsion applications are enhanced by high power-to-mass ratios for their electric power sources. At multi-megawatt levels, we can expect thrust production systems to be less than 5 kg/kWe. Application of nuclear electric propulsion to human Mars missions becomes an attractive alternative to nuclear thermal propulsion if the propulsion system is less than about 10 kg/kWe. Recent references have projected megawatt-plus nuclear electric sources at specific mass values from less than 1 kg/kWe to about 5 kg/kWe. Various assumptions are made regarding power generation cycle (turbogenerator; MHD) and reactor heat source design. The present paper compares heat source and power generation options on the basis of a parametric model that emphasizes heat transfer design and realizable hardware concepts. Pressure drop (important!) is

included in the power cycle analysis, and MHD and turbogenerator cycles arc compared. Results indicate that power source specific mass less than 5 kg/kWe is attainable, even if peak temperatures achievable are limited to 1500 K. Projections of specific mass less than 1 kg/kWe are unrealistic, even at the highest peak temperatures considered. [copyright] 2002 American Institute of Physics.
Author (AIP)
Electric Generators; Electric Propulsion; Mass Ratios; Nuclear Electric Propulsion; Nuclear Propulsion; Nuclear Reactors

20030046865

Multimegawatt NEP with vapor core reactor MHD

Smith, Blair; Knight, Travis; Anghaie, Samim; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 609-616; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA
Contract(s)/Grant(s): NAS8-01075; Copyright

Efforts at the Innovative Nuclear Space Power and Propulsion Institute have assessed the feasibility of combining gaseous or vapor core reactors with magnetohydrodynamic power generators to provide extremely high quality, high density, and low specific mass electrical power for space applications. Innovative shielding strategies are employed to maintain an effective but relatively low mass shield, which is the most dominating part of multi-megawatt space power systems. The fission driven magnetohydrodynamic generator produces tens of kilowatt DC power at specific mass of less than 0.5 kg/kW for the total power system. The MHD output with minor conditioning is coupled to magnetoplasmadynamic thruster to achieve an overall NEP system specific mass of less than 1.0 kg/kW for power levels above 20 MWe. Few other concepts would allow comparable ensuing payload savings and flexible mission abort options for manned flights to Mars for example. [copyright] 2002 American Institute of Physics.
Author (AIP)
Magnetohydrodynamic Generators; Magnetohydrodynamics; Nuclear Propulsion; Nuclear Reactors; Spacecraft; Spacecraft Propulsion; Technology Utilization

20030046863

Long-life space reactor for photon propulsion

Sawada, Tetsuo; Endo, Hiroshi; Netchaev, Alexandre; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 596-601; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA; Copyright

We have examined the core characteristics of Pu-based metallic alloy fuels used in the gallium-cooled fast reactor core. The objective of the reactor is to provide a high-temperature heat source for the photon engine to be used as the rocket propulsion in the deep space. In the concept, the liquid metal fast nuclear reactor uses metallic fuel in the liquid phase and high-temperature gallium coolant (inlet 2400 K, outlet 2600 K). The molten fuel is continuously supplied to the reactor during operation at full reactor power. The reactor power is controlled by a rotation of control drums with absorber material. [copyright] 2002 American Institute of Physics.
Author (AIP)
Coolants; Fast Nuclear Reactors; Fissile Fuels; Fission; Gallium; Liquid Alloys; Metal Fuels; Nuclear Fuel Elements; Nuclear Propulsion; Nuclear Reactors; Plutonium Alloys; Reactor Cores; Rocket Engines; Spacecraft Propulsion

20030046862

Phase 1 space fission propulsion system design considerations

Houts, Mike; Van Dyke, Melissa; Godfroy, Tom; Pedersen, Kevin; Martin, James; Dickens, Ricky; Salvail, Pat; Hrbud, Ivana; Carter, Robert; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 589-595; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA; Copyright

Fission technology can enable rapid, affordable access to any point in the solar system. If fission propulsion systems are to be developed to their full potential; however, near-term customers must be identified and initial fission systems successfully developed, launched, and operated. Studies conducted in fiscal year 2001 (IISTP, 2001) show that fission electric propulsion (FEP) systems operating at 80 kWe or above could enhance or enable numerous robotic outer solar system missions of interest. At these power levels it is possible to develop safe, affordable systems that meet mission performance requirements. In selecting the system design to pursue, seven evaluation criteria were identified: safety, reliability, testability, specific mass,

cost, schedule, and programmatic risk. A top-level comparison of three potential concepts was performed: an SP-100 based pumped liquid lithium system, a direct gas cooled system, and a heatpipe cooled system. For power levels up to at least 500 kWt (enabling electric power levels of 125-175 kWe, given 25-35% power conversion efficiency) the heatpipe system has advantages related to several criteria and is competitive with respect to all. Hardware-based research and development has further increased confidence in the heatpipe approach. Successful development and utilization of a 'Phase 1' fission electric propulsion system will enable advanced Phase 2 and Phase 3 systems capable of providing rapid, affordable access to any point in the solar system. [copyright] 2002 American Institute of Physics.
Author (AIP)
Cooling; Fission; Heat Pipes; Nuclear Fission; Nuclear Propulsion; Nuclear Reactors; Reactor Design; Solar System; Spacecraft; Spacecraft Propulsion; Systems Engineering

20030046861
Design and analysis of the SAFE-400 space fission reactor
Poston, David I.; Kapernick, Richard J.; Guffee, Ray M.; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 578-588; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM-STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA; Copyright

Ambitious solar system exploration missions in the near future will require robust power sources in the range of 10 to 200 kWe. Fission systems are well suited to provide safe, reliable, and economic power within this range. The Heatpipe Power System (HPS) is one possible approach for producing near-term, low-cost, space fission power. The goal of the HPS project is to devise an attractive space fission system that can be developed quickly and affordably. The primary ways of doing this are by using existing technology and by designing the system for inexpensive testing. If the system can be designed to allow highly prototypic testing with electrical heating, then an exhaustive test program can be carried out quickly and inexpensively, and thorough testing of the actual flight unit can be performed--which is a major benefit to reliability. Over the past 4 years, three small HPS proof-of-concept technology demonstrations have been conducted, and each has been highly successful. The Safe Affordable Fission Engine (SAFE) is an HPS reactor designed for producing electricity in space. The SAFE-400 is a 400-kWt reactor that has been designed to couple with a 100-kWe Brayton power system. The SAFE-400 contains 127 identical molybdenum (Mo) modules. A Mo/sodium heatpipe is at the center of each module, surrounded by three Mo tubes that each contain a rhenium-clad uranium-nitride fuel pin. Fission energy is conducted from the fuel pins to the heatpipes, which then carry the heat to a heatpipe-to-gas heat exchanger. This paper describes the design and analysis of the current SAFE-400 reactor design. [copyright] 2002 American Institute of Physics.
Author (AIP)
Design Analysis; Heat Pipes; Nuclear Fission; Nuclear Propulsion; Nuclear Reactors; Reactor Design; Reliability; Solar System; Space Exploration; Spacecraft; Spacecraft Propulsion

20030046832
An examination of emerging in-space propulsion concepts for one-year crewed mars missions
Pelaccio, Dennis G.; Rauwolf, Gerald A.; Maggio, Gaspare; Patel, Saroj; Sorensen, Kirk; AIP Conference Proceedings; January 14, 2002; ISSN 0094-243X; Volume 608, Issue no. 1, 365-373; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNATIONAL FORUM- STAIF 2002, 3-6 Feb 2002, Albuquerque, New Mexico, USA
Contract(s)/Grant(s): NAS8-99060; Copyright

A study was completed that provides a meaningful, even-handed, comparison assessment of promising candidate, in-space, exploration propulsion concepts to support emerging 'near-term' crewed Mars mission applications. In particular, the study examined the mission performance feasibility and risk of a number of near-, mid-, and far-term in-space propulsion concepts to support crewed Mars missions starting in 2018 that can have the crewed portion of the mission performed in one year or less. This study used exploration propulsion system team technology specialist advocates to identify seven meaningful, representative mission architecture scenarios to 'best' demonstrate the capability of such in-space propulsion technology options to support the near-term crewed Mars mission requirement. Additionally, a common set of top-level mission/system requirements was established for the study, which was incorporated in the assessment of all the mission options considered. Mission performance for abundant chemical (Ab-Chem), bimodal nuclear thermal rocket (BNTR), high power nuclear electric propulsion (HP-NEP), momentum tether/chemical, solar electric propulsion (SEP), solar electric propulsion/chemical (SEP-Chem) and Variable Specific Impulse Magnetoplasma Rocket (VASIMR) based missions were estimated for this quick trip, 2018 crewed Mars flight opportunity. Each of these mission options are characterized in terms of their overall mission performance capability, crewed mission duration, Initial Mass to Low Earth Orbit (IMLEO), which including dry and propellant weight required, overall mission time, number of flight elements (propulsion units/tank sets), and number of

Earth-to-Orbit (ETO) vehicle launches. Potential top-level development, implementation, and operational issues/risks for each mission scenario considered are also identified. [copyright] 2002 American Institute of Physics.
Author (AIP)
Earth Orbits; Electric Propulsion; Mars (Planet); Mars Missions; Nuclear Reactors; Rocket Engines; Rockets; Solar Corpuscular Radiation; Solar Wind; Spacecraft; Spacecraft Propulsion

20030045228
Propulsion technologies for exploration of the solar system and beyond (plenary)
Johnson, Les; Review of Scientific Instruments; February 2002; ISSN 0034-6748; Volume 73, Issue no. 2, 1079-1082; In English; Papers from the Ninth International Conference on Ion Sources, 2-7 September 2001, Berkeley, California, USA; Copyright

NASA's Advanced Space Transportation Program (ASTP) is investing in technologies to achieve a factor of 10 reduction in the cost of Earth orbital transportation and a factor of 2 reduction in propulsion system mass and travel time for planetary missions within the next 15 years. Since more than 70% of projected launches over the next 10 years will require propulsion systems capable of attaining destinations beyond low-Earth orbit, investment in in-space technologies will benefit a large percentage of future missions. The ASTP technology portfolio includes many advanced propulsion systems. From the next-generation ion propulsion system operating in the 5-10 kW range to fission-powered multikilowatt systems, substantial advances in spacecraft propulsion performance are anticipated. Some of the most promising technologies for achieving these goals use the environment of space itself for energy and propulsion and are generically called 'propellantless,' because they do not require onboard fuel to achieve thrust. An overview of state-of-the-art space propulsion technologies, such as solar and plasma sails, electrodynamic and momentum transfer tethers, and aeroassist and aerocapture, are described. Results of recent Earth-based technology demonstrations and space tests for many of these new propulsion technologies are discussed.
Author (AIP)
Apollo Soyuz Test Project; Cost Reduction; Ion Engines; Nuclear Propulsion; Nuclear Reactors; Orbital Maneuvers; Solar System; Space Missions; Space Probes; Space Transportation; Spacecraft; Spacecraft Propulsion

20030027869 NASA Glenn Research Center, Cleveland, OH, USA
Space Nuclear Power and Propulsion Systems Technology: Enabling Future Planetary Exploration. Segment 7: Power Management and Distribution
Soltis, James V.; February 1, 2003; In English, 1-2 Feb. 2003, Albuquerque, NM, USA; Original contains black and white illustrations; No Copyright; Avail: CASI; A04, Hardcopy

Control and integration of energy conversion in space nuclear reactor power systems is discussed. Specific topics include: Systems Engineering of the PMAD subsystem and interference with other subsystems, including environmental and mission unique considerations, and integration issues with payloads.
Author
Nuclear Propulsion; Energy Conversion; Systems Engineering; Spacecraft Control; Spacecraft Power Supplies; Nuclear Reactors

20030016687 NASA Glenn Research Center, Cleveland, OH USA
Experimental Results From a 2kW Brayton Power Conversion Unit
Hervol, David; Mason, Lee; Birchenough, Arthur; January 2003; In English, 2-6 Feb. 2003, Albuquerque, NM, USA; Original contains color illustrations
Contract(s)/Grant(s): RTOP 800-90-01
Report No.(s): NASA/TM-2003-211999; NAS 1.15:211999; E-13671; Copyright; Avail: CASI; A03, Hardcopy; Distribution as joint owner in the copyright

This paper presents experimental test results from operation of a 2 kWe Brayton power conversion unit. The Brayton converter was developed for a solar dynamic power system flight experiment planned for the Mir Space Station in 1997. The flight experiment was cancelled, but the converter was tested at Glenn Research Center as part of the Solar Dynamic Ground Test Demonstration system which included a solar concentrator, heat receiver, and space radiator. In preparation for the current testing, the heat receiver was removed and replaced with an electrical resistance heater, simulating the thermal input of a steady-state nuclear source. The converter was operated over a full range of thermal input power levels and rotor speeds to generate an overall performance map. The converter unit will serve as the centerpiece of a Nuclear Electric Propulsion Testbed at Glenn. Future potential uses for the Testbed include high voltage electrical controller development, integrated electric

thruster testing and advanced radiator demonstration testing to help guide high power Brayton technology development for Nuclear Electric Propulsion (NEP).
Author
Brayton Cycle; Power Converters; Nuclear Electric Propulsion; Energy Conversion Efficiency; Nuclear Electric Power Generation

20030014643 NASA Glenn Research Center, Cleveland, OH USA
Vehicle and Mission Design Options for the Human Exploration of Mars/Phobos Using 'Bimodal' NTR and LANTR Propulsion
Borowski, Stanley K.; Dudzinski, Leonard A.; McGuire, Melissa L.; December 2002; In English, 13-15 Jul. 1998, Cleveland, OH, USA; Original contains color illustrations
Contract(s)/Grant(s): NAS3-27186; RTOP 953-20-0C
Report No.(s): NASA/TM-1998-208834/REV1; NAS 1.15:208834/REV1; E-11445-1/REV1; AIAA Paper 98-3883/REV1; Copyright; Avail: CASI; A04, Hardcopy; Distribution as joint owner in the copyright

The nuclear thermal rocket (NTR) is one of the leading propulsion options for future human missions to Mars because of its high specific impulse (1sp is approximately 850-1000 s) capability and its attractive engine thrust-to-weight ratio (approximately 3-10). To stay within the available mass and payload volume limits of a 'Magnum' heavy lift vehicle, a high performance propulsion system is required for trans-Mars injection (TMI). An expendable TMI stage, powered by three 15 thousand pounds force (klbf) NTR engines is currently under consideration by NASA for its Design Reference Mission (DRM). However, because of the miniscule burnup of enriched uranium-235 during the Earth departure phase (approximately 10 grams out of 33 kilograms in each NTR core), disposal of the TMI stage and its engines after a single use is a costly and inefficient use of this high performance stage. By reconfiguring the engines for both propulsive thrust and modest power generation (referred to as 'bimodal' operation), a robust, multiple burn, 'power-rich' stage with propulsive Mars capture and reuse capability is possible. A family of modular bimodal NTR (BNTR) vehicles are described which utilize a common 'core' stage powered by three 15 klbf BNTRs that produce 50 kWe of total electrical power for crew life support, an active refrigeration / reliquification system for long term, zero-boiloff liquid hydrogen (LH2) storage, and high data rate communications. An innovative, spine-like 'saddle truss' design connects the core stage and payload element and is open underneath to allow supplemental 'in-line' propellant tanks and contingency crew consumables to be easily jettisoned to improve vehicle performance. A 'modified' DRM using BNTR transfer vehicles requires fewer transportation system elements, reduces IMLEO and mission risk, and simplifies space operations. By taking the next logical step--use of the BNTR for propulsive capture of all payload elements into Mars orbit--the power available in Mars orbit grows to 150 kWe compared to 30 kWe for the DRM. Propulsive capture also eliminates the complex, higher risk aerobraking and capture maneuver which is replaced by a simpler reentry using a standardized, lower mass 'aerodescent' shell. The attractiveness of the 'all BNTR' option is further increased by the substitution of the lightweight, inflatable 'TransHab' module in place of the heavier, hard-shell hab module. Use of TransHab introduces the potential for propulsive recovery and reuse of the BNTR / Earth return vehicle (ERV). It also allows the crew to travel to and from Mars on the same BNTR transfer vehicle thereby cutting the duration of the ERV mission in half--from approximately 4.7 to 2.5 years. Finally, for difficult Mars options, such as Phobos rendezvous and sample return missions, volume (not mass) constraints limit the performance of the 'all LH2' BNTR stage. The use of 'LOX-augmented' NTR (LANTR) engines, operating at a modest oxygen-to-hydrogen mixture ratio (MR) of 0.5, helps to increase 'bulk' propellant density and total thrust during the TMI burn. On all subsequent burns, the bimodal LANTR engines operate on LH2 only (MR=0) to maximize vehicle performance while staying within the mass limits of two Magnum launches.
Author
Nuclear Propulsion; Mars Missions; In Situ Resource Utilization; High Thrust; Spacecraft Propulsion

20030012712 NASA Langley Research Center, Hampton, VA USA
Human Factors and Information Operation for a Nuclear Power Space Vehicle
Trujillo, Anna C.; Brown-VanHoozer, S. Alenka; [2002]; In English, 9-13 Jun. 2002, Hollywood, FL, USA
Contract(s)/Grant(s): DE-AC05-00OR-22725; No Copyright; Avail: CASI; A02, Hardcopy

This paper describes human-interactive systems needed for a crewed nuclear-enabled space mission. A synthesis of aircraft engine and nuclear power plant displays, biofeedback of sensory input, virtual control, brain mapping for control process and manipulation, and so forth are becoming viable solutions. These aspects must maintain the crew's situation

awareness and performance, which entails a delicate function allocation between crew and automation.
Author
Human Factors Engineering; Nuclear Propulsion; Spacecraft; Man Machine Systems; Space Missions; Display Devices

20030007870

Ablation Radiation Shields for Nuclear Fusion Rockets

Coreano, Luis; Cassenti, Brice N.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 502-509; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

Pulse nuclear propulsion has been the subject of extensive studies since the 1960's. Early concepts examined external pulse propulsion where small critical mass nuclear devices are ejected from the rear of the rocket. A pusher plate absorbs some of the energy form the detonation, which ablates the plate and provides thrust for the rocket. It is also possible to have the device detonate in an enclosed chamber (i.e., internal pulse propulsion). Again, in this case, ablation is the primary method for applying the thrust. Ablation can not only provide thrust but it can also aid in the dissipation of the heat in a neutron radiation shield. Since high-energy neutrons will be abundant in deuterium-tritium fusion reactions, fusion rockets that use this reaction usually are designed with a radiator to dissipate the heat from the shield. These radiators usually require a considerable mass. Carbon and tungsten ablative shields may be considerably more effective. Ablation and radiation are compared as mechanisms to dissipate the heat. Although ablation is shown to provide a considerable mass saving heat loses at the surfaces will create thermal gradients that will adversely effect the ablation rate, and may significantly increase the mass loss. [copyright] 2003 American Institute of Physics
Author (AIP)
Carbon; Flux (Rate); Fusion Reactors; Heat Transfer; Neutrons; Nuclear Fusion; Nuclear Propulsion; Radiation Protection; Reactor Materials; Shielding; Spacecraft Propulsion; Tungsten

20030006861

High Power Nuclear Electric Propulsion (NEP) for Cargo and Propellant Transfer Missions in Cislunar Space

Falck, Robert D.; Borowski, Stanley K.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 844-852; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

The performance of Nuclear Electric Propulsion (NEP) in transporting cargo and propellant from Low Earth Orbit (LEO) to the first Earth-Moon Lagrange point (EML1) is examined. The baseline NEP vehicle utilizes a fission reactor system with Brayton power conversion for electric power generation to power multiple liquid hydrogen magnetoplasmadynamic (MPD) thrusters. Vehicle characteristics and performance levels are based on technology availability in a fifteen to twenty year timeframe. Results of numerical trajectory analyses are also provided. [copyright] 2003 American Institute of Physics
Author (AIP)
Cislunar Space; Electric Propulsion; Jupiter (Planet); Low Earth Orbits; Nuclear Electric Propulsion; Nuclear Propulsion; Nuclear Reactors; Propellant Transfer; Spacecraft; Spacecraft Propulsion

20030006860

High Power MPD Nuclear Electric Propulsion (NEP) for Artificial Gravity HOPE Missions to Callisto

McGuire, Melissa L.; Borowski, Stanley K.; Mason, Lee M.; Gilland, James; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 837-843; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

The following paper documents the results of a one-year multi-center NASA study on the prospect of sending humans to Jupiter's moon, Callisto, using an all Nuclear Electric Propulsion (NEP) space transportation system architecture with magnetoplasmadynamic (MPD) thrusters. The fission reactor system utilizes high temperature uranium dioxide (UO2) in tungsten (W) metal matrix 'cermet' fuel and electricity is generated using advanced dynamic Brayton power conversion technology. The mission timeframe assumes on-going human Moon and Mars missions and existing space infrastructure to

support launch of cargo and crewed spacecraft to Jupiter in 2041 and 2045, respectively. [copyright] 2003 American Institute of Physics
Author (AIP)
Architecture (Computers); Artificial Gravity; Electric Propulsion; Electromagnetic Propulsion; Jupiter (Planet); Magnetoplasmadynamic Thrusters; Natural Satellites; Nuclear Electric Propulsion; Nuclear Propulsion; Nuclear Reactors; Space Transportation System; Spacecraft; Spacecraft Propulsion

20030006859
'Bimodal' Nuclear Thermal Rocket (BNTR) Propulsion for an Artificial Gravity HOPE Mission to Callisto
Borowski, Stanley K.; McGuire, Melissa L.; Mason, Lee M.; Gilland, James H.; Packard, Thomas W.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 829-836; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

This paper summarizes the results of a year long, multi-center NASA study which examined the viability of nuclear fission propulsion systems for Human Outer Planet Exploration (HOPE). The HOPE mission assumes a crew of six is sent to Callisto. Jupiter's outermost large moon, to establish a surface base and propellant production facility. The Asgard asteroid formation, a region potentially rich in water-ice, is selected as the landing site. High thrust BNTR propulsion is used to transport the crew from the Earth-Moon L1 staging node to Callisto then back to Earth in less than 5 years. Cargo and LH2 'return' propellant for the piloted Callisto transfer vehicle (PCTV) is pre-deployed at the moon (before the crew's departure) using low thrust, high power, nuclear electric propulsion (NEP) cargo and tanker vehicles powered by hydrogen magnetoplasmadynamic (MPD) thrusters. The PCTV is powered by three 25 klbf BNTR engines which also produce 50 kWe of power for crew life support and spacecraft operational needs. To counter the debilitating effects of long duration space flight ([approx]855 days out and [approx]836 days back) under '0-gE' conditions, the PCTV generates an artificial gravity environment of '1-gE' via rotation of the vehicle about its center-of-mass at a rate of [approx]4 rpm. After [approx]123 days at Callisto, the 'refueled' PCTV leaves orbit for the trip home. Direct capsule re-entry of the crew at mission end is assumed. Dynamic Brayton power conversion and high temperature uranium dioxide (UO2) in tungsten metal 'cermet' fuel is used in both the BNTR and NEP vehicles to maximize hardware commonality. Technology performance levels and vehicle characteristics are presented, and requirements for PCTV reusability are also discussed. [copyright] 2003 American Institute of Physics
Author (AIP)
Artificial Gravity; Electric Propulsion; Jupiter (Planet); Natural Satellites; Nuclear Fission; Nuclear Propulsion; Nuclear Reactors; Propulsion System Configurations; Propulsion System Performance; Rocket Engines; Rockets; Spacecraft; Spacecraft Propulsion

20030006856
SAFE Testing Nuclear Rockets Economically
Howe, Steven D.; Travis, Bryan; Zerkle, David K.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 805-813; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

Several studies over the past few decades have recognized the need for advanced propulsion to explore the solar system. As early as the 1960s, Werner Von Braun and others recognized the need for a nuclear rocket for sending humans to Mars. The great distances, the intense radiation levels, and the physiological response to zero-gravity all supported the concept of using a nuclear rocket to decrease mission time. These same needs have been recognized in later studies, especially in the Space Exploration Initiative in 1989. One of the key questions that has arisen in later studies, however, is the ability to test a nuclear rocket engine in the current societal environment. Unlike the Rover/NERVA programs in the 1960s, the rocket exhaust can no longer be vented to the open atmosphere. As a consequence, previous studies have examined the feasibility of building a large-scale version of the Nuclear Furnace Scrubber that was demonstrated in 1971. We have investigated an alternative that would deposit the rocket exhaust along with any entrained fission products directly into the ground. The Subsurface Active Filtering of Exhaust, or SAFE, concept would allow variable sized engines to be tested for long times at a modest expense. A system overview, results of preliminary calculations, and cost estimates of proof of concept demonstrations are presented. The results indicate that a nuclear rocket could be tested at the Nevada Test Site for under $20 M. [copyright] 2003 American Institute of Physics
Author (AIP)
Cost Estimates; Nuclear Propulsion; Nuclear Reactors; Research Projects; Solar System; Spacecraft Propulsion; Systems Analysis; Tests

20030006840

A Closed Brayton Power Conversion Unit Concept for Nuclear Electric Propulsion for Deep Space Missions

Joyner, Claude Russell, II; Fowler, Bruce; Matthews, John; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 677-684; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

In space, whether in a stable satellite orbit around a planetary body or traveling as a deep space exploration craft, power is just as important as the propulsion. The need for power is especially important for in-space vehicles that use Electric Propulsion. Using nuclear power with electric propulsion has the potential to provide increased payload fractions and reduced mission times to the outer planets. One of the critical engineering and design aspects of nuclear electric propulsion at required mission optimized power levels is the mechanism that is used to convert the thermal energy of the reactor to electrical power. The use of closed Brayton cycles has been studied over the past 30 or years and shown to be the optimum approach for power requirements that range from ten to hundreds of kilowatts of power. It also has been found to be scalable to higher power levels. The Closed Brayton Cycle (CBC) engine power conversion unit (PCU) is the most flexible for a wide range of power conversion needs and uses state-of-the-art, demonstrated engineering approaches. It also is in use with many commercial power plants today. The long life requirements and need for uninterrupted operation for nuclear electric propulsion demands high reliability from a CBC engine. A CBC engine design for use with a Nuclear Electric Propulsion (NEP) system has been defined based on Pratt & Whitney's data from designing long-life turbo-machines such as the Space Shuttle turbopumps and military gas turbines and the use of proven integrated control/health management systems (EHMS). An integrated CBC and EHMS design that is focused on using low-risk and proven technologies will over come many of the life-related design issues. This paper will discuss the use of a CBC engine as the power conversion unit coupled to a gas-cooled nuclear reactor and the design trends relative to its use for powering electric thrusters in the 25 kWe to 100kWe power level. [copyright] 2003 American Institute of Physics

Author (AIP)

Brayton Cycle; Deep Space; Electric Generators; High Temperature; Nuclear Electric Propulsion; Nuclear Propulsion; Nuclear Reactors; Space Exploration; Space Missions; Spacecraft; Spacecraft Power Supplies; Spacecraft Propulsion; Temperature Effects; Turbines

20030006831

Radiator Concepts for Nuclear Powered Brayton Conversion Systems

Angirasa, Devarakonda; Mason, Lee S.; Shaltens, Richard K.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 605-612; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

This paper reviews the technical background for the development of Brayton power conversion system for Nuclear Electric Propulsion (NEP). The Brayton system is outlined in terms of its subsystems and their components. The heat rejection subsystem is examined. Some potential concepts are developed for the heat rejection subsystems. The requisite analyses for the design of radiators were developed. Theoretical and numerical aspects are discussed. Technological issues with reference to the radiators are highlighted. [copyright] 2003 American Institute of Physics

Author (AIP)

Brayton Cycle; Electric Generators; Nuclear Electric Propulsion; Spacecraft Power Supplies; Turbogenerators

20030006830

Technology Concept for a Near-Term Closed Brayton Cycle Power Conversion Unit

Foti, John; Halsey, Dave; Bauch, Tim; Smith, Glen; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 597-604; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

There is a need in the space science community for nuclear-powered electric propulsion systems to enable high-value, deep space and planetary exploration. Certain missions are driven by once-in-a-lifetime or highly infrequent occurrences that require the near-term development of a flight-capable nuclear space power and electric propulsion system in order to take advantage of the scientific opportunity. The broader applicability of Brayton power systems to the commercial and military aircraft markets has provided fertile ground for the continued development and implementation of new technologies applicable to a closed Brayton cycle space Power Conversion Unit (PCU). One concept for effectively achieving a near-term Brayton

space power capability is based on the development work associated with the Integrated Power Unit (IPU). This unit embodies the state of the art in turbomachinery, generators, bearing systems and electric power management and distribution capability that can readily be evolved into a closed Brayton cycle PCU. This paper provides an overview of aircraft-based Brayton power system technologies, their implementation into the IPU and one approach for leveraging this capability into a near-term closed Brayton cycle space power conversion unit. [copyright] 2003 American Institute of Physics
Author (AIP)
Aerospace Systems; Brayton Cycle; Closed Cycles; Deep Space; Electric Generators; Nuclear Electric Propulsion; Space Exploration; Spacecraft Power Supplies; Spacecraft Propulsion; Technological Forecasting; Turbogenerators

20030006824
A Nuclear-Powered Laser-Accelerated Plasma Propulsion System
Kammash, Terry; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 547-552; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

Recent experiments at the University of Michigan and other laboratories throughout the world have demonstrated that ultrafast (very short pulse length) lasers can accelerate charged particles to relativistic speeds. The terrawatt laser at the University of Michigan has generated a beam of protons containing more than 1010 particles at a mean energy of over one Mev while the petawatt laser at the Lawrence Livermore National Laboratory has produced proton beams containing more than 1014 particles with maximum energy of 58 Mev and a mean energy of about 6 Mev. Using the latter data as a basis for a present-day LAPPS (Laser Accelerated Plasma Propulsion System) propulsion device we show that it can produce a specific impulse of several million seconds albeit at a fraction of a Newton of thrust. We show that if the thrust can be increased to a modest 25 Newtons a fly-by robotic interstellar mission to 10,000 AU can be achieved in about 26 years, while a round trip to Mars will be accomplished in about 6 months. In both instances a one MWe nuclear power system with a mass of about 5 MT will be needed to drive the laser, and the recently announced NASA’s Nuclear Space Initiative should be able to address such reactors in the near future. [copyright] 2003 American Institute of Physics
Author (AIP)
Charged Particles; Electric Generators; Electric Propulsion; Laser Applications; Laser Plasmas; Nuclear Propulsion; Plasmas (Physics); Proton Beams; Pulsed Lasers; Spacecraft Power Supplies; Spacecraft Propulsion

20030006822
Non-Nuclear NEP System Testing
Hrbud, Ivana; Goodfellow, Keith; Van Dyke, Melissa; Houts, Mike; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 533-539; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

The Safe Affordable Fission Engine (SAFE) test series addresses Phase 1 Space Fission Systems issues in particular non-nuclear testing and system integration issues leading to the testing and non-nuclear demonstration of a 400-kW fully integrated flight unit. The first part of the SAFE 30 test series demonstrated operation of the simulated nuclear core and heat pipe system. Experimental data acquired in a number of different test scenarios will validate existing computational models, demonstrated system flexibility (fast start-ups, multiple start-ups/shut downs), simulate predictable failure modes and operating environments. The objective of the second part is to demonstrate an integrated propulsion system consisting of a core, conversion system and a thruster where the system converts thermal heat into jet power. This end-to-end system demonstration sets a precedent for ground testing of nuclear electric propulsion systems. The paper describes the SAFE 30 end-to-end system demonstration and its subsystems. [copyright] 2003 American Institute of Physics
Author (AIP)
Aerospace Systems; Engine Tests; Failure Analysis; Heat Pipes; Nuclear Propulsion; Nuclear Reactors; Reactor Safety; Spacecraft Propulsion; Systems Integration; Tests

20030006811
Direct-Drive Gas-Cooled Reactor Power System: Concept and Preliminary Testing
Wright, S. A.; Lipinski, R. J.; Godfroy, T. J.; Bragg-Sitton, S. M.; Van Dyke, M. K.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 445-450; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA

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This paper describes the concept and preliminary component testing of a gas-cooled. UN-fueled, pin-type reactor which uses He/Xe gas that goes directly into a recuperated Brayton system to produce electricity for nuclear electric propulsion. This Direct-Drive Gas-Cooled Reactor (DDG) is designed to be subcritical under water or wet-sand immersion in case of a launch accident. Because the gas-cooled reactor can directly drive the Brayton turbomachinery, it is possible to configure the system such that there are no external surfaces or pressure boundaries that are refractory metal, even though the gas delivered to the turbine is 1144 K. The He/Xe gas mixture is a good heat transport medium when flowing, and a good insulator when stagnant. Judicious use of stagnant cavities as insulating regions allows transport of the 1144-K gas while keeping all external surfaces below 900 K. At this temperature super-alloys (Hastelloy or Inconel) can be used instead of refractory metals. Super-alloys reduce the technology risk because they are easier to fabricate than refractory metals, we have a much more extensive knowledge base on their characteristics, and, because they have a greater resistance to oxidation, system testing is eased. The system is also relatively simple in its design: no additional coolant pumps, heat exchanger, or freeze-thaw systems are required. Key to success of this concept is a good knowledge of the heat transfer between the fuel pins and the gas, as well as the pressure drop through the system. This paper describes preliminary testing to obtain this key information, as well as experience in demonstrating electrically heated testing of simulated reactor components. [copyright] 2003 American Institute of Physics

Author (AIP)

Cooling; Electric Generators; Fissile Fuels; Fission; Gas Cooled Reactors; Heat Resistant Alloys; Heat Transfer; Mechanical Drives; Nuclear Fission; Nuclear Propulsion; Nuclear Reactors; Reactor Design; Spacecraft Power Supplies; Spacecraft Propulsion; Tests

20030006810

Design and Development of the MITEE-B Bi-Modal Nuclear Propulsion Engine

Paniagua, John C.; Powell, James R.; Maise, George; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 438-444; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

Previous studies of compact, ultra-lightweight high performance nuclear thermal propulsion engines have concentrated on systems that only deliver high thrust. However, many potential missions also require substantial amounts of electric power. Studies of a new, very compact and lightweight bi-modal nuclear engine that provides both high propulsive thrust and high electric power for planetary science missions are described. The design is a modification of the MITEE nuclear thermal engine concept that provided only high propulsive thrust. In the new design, MITEE-B, separate closed cooling circuits are incorporated into the reactor, which transfers useful amounts of thermal energy to a small power conversion system that generates continuous electric power over the full life of the mission, even when the engine is not delivering propulsive thrust. Two versions of the MITEE-B design are described and analyzed. Version 1 generates 1 kW(e) of continuous power for control of the spacecraft, sensors, data transmission, etc. This power level eliminates the need for RTG's on missions to the outer planets, and allowing considerably greater operational capability for the spacecraft. This, plus its high thrust and high specific impulse propulsive capabilities, makes MITEE-B very attractive for such missions. In Version 2, of MITEE-B, a total of 20 kW(e) is generated, enabling the use of electric propulsion. The combination of high open cycle propulsion thrust (20,000 Newtons) with a specific impulse of [approx]1000 seconds for short impulse burns, and long term (months to years), electric propulsion greatly increases MITEE's [Delta]V capability. Version 2 of MITEE-B also enables the production and replenishment of H2 propellant using in-situ resources, such as electrolysis of water from the ice sheet on Europa and other Jovian moons. This capability would greatly increase the [Delta]V available for certain planetary science missions. The modifications to the MITEE multiple pressure tube/fuel element assembly to achieve bi-modal capability are modest. Small diameter coolant tubes are bonded to the surface of the MITEE cold frits that enclose the fuel elements. When the MITEE-B is not operating with H2 propellant to generate high thrust, the reactor continues to operate at low thermal, which is transferred to the closed coolant circuit. Three electric power generations are examined for MITEE-B: closed Brayton, Stirling, and a conventional steam cycle with a mini-turbine. The Stirling and steam cycles have the lowest specific masses in kg/kW(e). Both appear practical for MITEE-B. [copyright] 2003 American Institute of Physics

Author (AIP)

Electric Generators; High Thrust; Mass; Nuclear Propulsion; Nuclear Reactors; Propulsion; Roving Vehicles; Spacecraft Power Supplies

20030006809

MITEE-B: A Compact Ultra Lightweight Bi-Modal Nuclear Propulsion Engine for Robotic Planetary Science Missions

Powell, James; Maise, George; Paniagua, John; Borowski, Stanley; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 429-437; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

Nuclear thermal propulsion (NTP) enables unique new robotic planetary science missions that are impossible with chemical or nuclear electric propulsion systems. A compact and ultra lightweight bi-modal nuclear engine, termed MITEE-B (MInature ReacTor EnginE - Bi-Modal) can deliver 1000's of kilograms of propulsive thrust when it operates in the NTP mode, and many kilowatts of continuous electric power when it operates in the electric generation mode. The high propulsive thrust NTP mode enables spacecraft to land and takeoff from the surface of a planet or moon, to hop to multiple widely separated sites on the surface, and virtually unlimited flight in planetary atmospheres. The continuous electric generation mode enables a spacecraft to replenish its propellant by processing in-situ resources, provide power for controls, instruments, and communications while in space and on the surface, and operate electric propulsion units. Six examples of unique and important missions enabled by the MITEE-B engine are described, including: (1) Pluto lander and sample return; (2) Europa lander and ocean explorer; (3) Mars Hopper; (4) Jupiter atmospheric flyer; (5) SunBurn hypervelocity spacecraft; and (6) He3 mining from Uranus. Many additional important missions are enabled by MITEE-B. A strong technology base for MITEE-B already exists. With a vigorous development program, it could be ready for initial robotic science and exploration missions by 2010 AD. Potential mission benefits include much shorter in-space times, reduced IMLEO requirements, and replenishment of supplies from in-situ resources. [copyright] 2003 American Institute of Physics

Author (AIP)

Chemical Propulsion; Electric Generators; Mass; Nuclear Electric Propulsion; Nuclear Propulsion; Nuclear Reactors; Propulsion; Propulsion System Configurations; Propulsion System Performance; Research Projects; Roving Vehicles; Space Missions; Spacecraft Power Supplies

20030006807

Pin-Type Gas Cooled Reactor for Nuclear Electric Propulsion

Wright, Steven A.; Lipinski, Ronald J.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 408-419; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA

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This paper describes a point design for a pin-type Gas-Cooled Reactor concept that uses a fuel pin design similar to the SP100 fuel pin. The Gas-Cooled Reactor is designed to operate at 100 kWe for 7 years plus have a reduced power mode of 20% power for a duration of 5 years. The power system uses a gas-cooled, UN-fueled, pin-type reactor to heat He/Xe gas that flows directly into a recuperated Brayton system to produce electricity. Heat is rejected to space via a thermal radiator that unfolds in space. The reactor contains approximately 154 kg of 93.15 % enriched UN in 313 fuel pins. The fuel is clad with rhenium-lined Nb-1Zr. The pressures vessel and ducting are cooled by the 900 K He/Xe gas inlet flow or by thermal radiation. This permits all pressure boundaries to be made of superalloy metals rather than refractory metals, which greatly reduces the cost and development schedule required by the project. The reactor contains sufficient rhenium (a neutron poison) to make the reactor subcritical under water immersion accidents without the use of internal shutdown rods. The mass of the reactor and reflectors is about 750 kg. [copyright] 2003 American Institute of Physics

Author (AIP)

Cooling; Electric Generators; Fuels; Gas Cooled Reactors; Heat Transfer; Mass; Nuclear Electric Propulsion; Nuclear Propulsion; Nuclear Reactors; Spacecraft Power Supplies; Spacecraft Propulsion

20030006805

High Efficiency Thermoelectrics in NEP Reactor Power Systems

Allen, Daniel T.; Ghamaty, Saeid; Elsner, Norbert B.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 384-396; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

Thermoelectric space reactor power systems that utilize Multi-Layer Quantum Well (MLQW) technology are presented and discussed in the context of Nuclear Electric Propulsion (NEP). Quantum wells are one of the recent developments in

low-dimensional thermoelectric materials that show a factor of 2.5 increase in the thermoelectric figure of merit. This breakthrough in converter performance promises higher efficiency power generating devices. The MLQW under development at Hi-Z Technology, Inc., applied to space systems provides the design flexibility traditionally available with thermoelectric conversion in reactor power systems with higher performance. The reactor concept evaluated is the Heatpipe Power System (HPS) reactor. [copyright] 2003 American Institute of Physics
Author (AIP)
Electric Generators; Nuclear Electric Propulsion; Nuclear Reactors; Quantum Wells; Semiconductors (Materials); Spacecraft Power Supplies; Spacecraft Propulsion; Thermoelectric Power Generation; Thermoelectricity; Transport Properties

20020089589 Air Force Research Lab., Edwards AFB, CA USA
Comparison of Orbit Transfer Vehicle Concepts Utilizing Mid-Term Power and Propulsion Options
Gulczinski, Frank S., III; Schilling, John H.; May 14, 2002; In English
Report No.(s): AD-A406811; No Copyright; Avail: CASI; A01, Hardcopy

The recent announcement of a national nuclear space flight initiative1 has rekindled interest in nuclear propulsion options within the spacecraft propulsion community. Therefore, the Air Force Research Laboratory Propulsion Directorate (AFRL/PRSS) has decided to reexamine the value of utilizing nuclear propulsion for orbit transit and the repositioning of future Air Force space assets. A trade study was conducted with the assumption that technologies had matured to the 2010 level. A comparison was made between advanced chemical, solar thermal, solar electric, and nuclear electric for both expendable and reusable mission concepts, with a particular interest in options that resulted in trip times of 30 days or less. Results show that for expendable stages both solar thermal and, to a greater degree, solar electric propulsion systems can provide a significant increase in payload delivered from LEO to GEO within the required trip times. The solar electric concepts utilize clustered Hall thrusters, thin film photovoltaic solar arrays for power generation, and advanced power processing topologies for power conversion. The nuclear electric option became advantageous for trip times greater than 30 days. For reusable vehicles, where payload and fuel are supplied to a reusable propulsion tug module, similar results were calculated based on trip time.
DTIC
Orbit Transfer Vehicles; Spacecraft Propulsion; Photovoltaic Cells; Nuclear Electric Propulsion

20020084995 NASA Marshall Space Flight Center, Huntsville, AL USA
Benefits of Nuclear Electric Propulsion for Outer Planet Exploration
Kos, Larry; Johnson, Les; Jones, Jonathan; Trausch, Ann; Eberle, Bill; Woodcock, Gordon; Brady, Hugh J., Technical Monitor; [2002]; In English; 38th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, 7-10 Jul. 2002, Indianapolis, IN, USA; Original contains color illustrations
Report No.(s): AIAA Paper 2002-3548; No Copyright; Avail: CASI; A02, Hardcopy

Nuclear electric propulsion (NEP) offers significant benefits to missions for outer planet exploration. Reaching outer planet destinations, especially beyond Jupiter, is a struggle against time and distance. For relatively near missions, such as a Europa lander, conventional chemical propulsion and NEP offer similar performance and capabilities. For challenging missions such as a Pluto orbiter, neither chemical nor solar electric propulsion are capable while NEP offers acceptable performance. Three missions are compared in this paper: Europa lander, Pluto orbiter, and Titan sample return, illustrating how performance of conventional and advanced propulsion systems vary with increasing difficulty. The paper presents parametric trajectory performance data for NEP. Preliminary mass/performance estimates are provided for a Europa lander and a Titan sample return system, to derive net payloads for NEP. The NEP system delivers payloads and ascent/descent spacecraft to orbit around the target body, and for sample return, delivers the sample carrier system from Titan orbit to an Earth transfer trajectory. A representative scientific payload 500 kg was assumed, typical for a robotic mission. The resulting NEP systems are 100-kWe class, with specific impulse from 6000 to 9000 seconds.
Author
Nuclear Electric Propulsion; Chemical Propulsion; Trajectories; Solar Electric Propulsion

20020081342 NASA Glenn Research Center, Cleveland, OH USA

Radioisotope Electric Propulsion for Fast Outer Planetary Orbiters

Oleson, Steven; Benson, Scott; Gefert, Leon; Patterson, Michael; Schreiber, Jeffrey; September 2002; In English, 7-10 Jul. 2002, Indianapolis, IN, USA

Contract(s)/Grant(s): RTOP 344-96-8D

Report No.(s): NASA/TM-2002-211893; NAS 1.15:211893; E-13575; AIAA Paper 2002-3967; No Copyright; Avail: CASI; A03, Hardcopy

Recent interest in outer planetary targets by the Office of Space Science has spurred the search for technology options to enable relatively quick missions to outer planetary targets. Several options are being explored including solar electric propelled stages combined with aerocapture at the target and nuclear electric propulsion. Another option uses radioisotope powered electric thrusters to reach the outer planets. Past work looked at using this technology to provide faster flybys. A better use for this technology is for outer planet orbiters. Combined with medium class launch vehicles and a new direct trajectory these small, sub-kilowatt ion thrusters and Stirling radioisotope generators were found to allow missions as fast as 5 to 12 years for objects from Saturn to Pluto, respectively. Key to the development is light spacecraft and science payload technologies.

Author

Nuclear Electric Propulsion; Radioactive Isotopes; Gas Giant Planets; Grand Tours; Aerocapture

20020068818 State Univ. of East Tennessee, Johnson City, TN USA

3-D Visualization in Support of Advanced Propulsion

Kyzar, Jan P.; Research Reports: 2001 NASA/ASEE Summer Faculty Fellowship Program; July 2002, XXVIII-1 - XXVIII-5; In English; No Copyright; Avail: CASI; A01, Hardcopy

The tools and techniques of three-dimensional computer imaging and animation are more than just a bag of new tricks. They have the power to communicate, inspire, and move the minds of people. Through these animations, it is the intent of the author to help the Propulsion Research Center educate and inspire the public about the vast possibilities of space exploration using Fission Electric Propulsion systems.

Derived from text

Computer Animation; Space Exploration; Education; Presentation

20020067442 NASA Marshall Space Flight Center, Huntsville, AL USA

In-Space Propulsion Program Overview and Status

Carroll, Carol; Johnson, Les; Baggett, Randy; [2002]; In English, 17-21 Mar. 2003, Toulouse, France; No Copyright; Avail: Other Sources; Abstract Only

NASA's In-Space Propulsion (ISP) Program is designed to develop advanced propulsion technologies that can enable or greatly enhance near and mid-term NASA science missions by significantly reducing cost, mass, and/or travel times. These technologies include: Electric Propulsion (Solar and Nuclear Electric) [note: The Nuclear Electric Propulsion work will be transferred to the NSI program in FY03]; Propellantless Propulsion (aerocapture, solar sails, plasma sails, and momentum exchange tethers); Advanced Chemical Propulsion. The ISP approach to identifying and prioritizing these most promising technologies is to use mission analysis and subsequent peer review. These technologies under consideration are mid-Technology Readiness Level (TRL) up to TRL-6 for incorporation into mission planning within three - five years of initiation. In addition, maximum use of open competition is encouraged to seek optimum solutions under ISP. Several NASA Research Announcements (NRAs) have been released asking industry, academia and other organizations to propose propulsion technologies designed to improve our ability to conduct scientific study of the outer planets and beyond. The ISP Program is managed by NASA HQ (Headquarters) and implemented by the Marshall Space Flight Center in Huntsville, Alabama.

Author

NASA Programs; Technology Assessment; Research and Development; Spacecraft Propulsion

20020067411 NASA Marshall Space Flight Center, Huntsville, AL USA

The FRC Acceleration Space Thruster (FAST) Experiment

Martin, Adam; Eskridge, Richard; Houts, Mike; Slough, John; Rodgers, Stephen L., Technical Monitor; [2002]; In English; Advanced Space Propulsion Workshop, 4-6 Jun. 2002, Pasadena, CA, USA; No Copyright; Avail: Other Sources; Abstract Only

The objective of the FRC (Field Reversed Configuration) Acceleration Space Thruster (FAST) Experiment is to investigate the use of a repetitive FRC source as a thruster, specifically for an NEP (nuclear electric propulsion) system. The

Field Reversed Configuration is a plasmoid with a closed poloidal field line structure, and has been extensively studied as a fusion reactor core. An FRC thruster works by repetitively producing FRCs and accelerating them to high velocity. An FRC thruster should be capable of I(sub sp)'s in the range of 5,000 - 25,000 seconds and efficiencies in the range of 60 - 80 %. In addition, they can have thrust densities as high as 10(exp 6) N/m2, and as they are inductively formed, they do not suffer from electrode erosion. The jet-power should be scalable from the low to the high power regime. The FAST experiment consists of a theta-pinch formation chamber, followed by an acceleration stage. Initially, we will produce and accelerate single FRCs. The initial focus of the experiment will be on the ionization, formation and acceleration of a single plasmoid, so as to determine the likely efficiency and I(sub sp). Subsequently, we will modify the device for repetitive burst-mode operation (5-10 shots). A variety of diagnostics are or will be available for this work, including a HeNe interferometer, high-speed cameras, and a Thomson-scattering system. The status of the experiment will be described.
Author
Nuclear Electric Propulsion; Plasmas (Physics); Spacecraft Propulsion; Rocket Engines

20020066161 NASA Marshall Space Flight Center, Huntsville, AL USA
Selection and Prioritization of Advanced Propulsion Technologies for Future Space Missions
Eberle, Bill; Farris, Bob; Johnson, Les; Jones, Jonathan; Kos, Larry; Woodcock, Gordon; Brady, Hugh J., Technical Monitor; [2002]; In English; 38th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, 7-10 Jul. 2002, Indianapolis, IN, USA; No Copyright; Avail: CASI; A02, Hardcopy

The exploration of our solar system will require spacecraft with much greater capability than spacecraft which have been launched in the past. This is particularly true for exploration of the outer planets. Outer planet exploration requires shorter trip times, increased payload mass, and ability to orbit or land on outer planets. Increased capability requires better propulsion systems, including increased specific impulse. Chemical propulsion systems are not capable of delivering the performance required for exploration of the solar system. Future propulsion systems will be applied to a wide variety of missions with a diverse set of mission requirements. Many candidate propulsion technologies have been proposed but NASA resources do not permit development of a] of them. Therefore, we need to rationally select a few propulsion technologies for advancement, for application to future space missions. An effort was initiated to select and prioritize candidate propulsion technologies for development investment. The results of the study identified Aerocapture, 5 - 10 KW Solar Electric Ion, and Nuclear Electric Propulsion as high priority technologies. Solar Sails, 100 Kw Solar Electric Hall Thrusters, Electric Propulsion, and Advanced Chemical were identified as medium priority technologies. Plasma sails, momentum exchange tethers, and low density solar sails were identified as high risk/high payoff technologies.
Author
Space Missions; Propulsion System Performance; Propulsion System Configurations; Nuclear Electric Propulsion

20020060123 NASA Marshall Space Flight Center, Huntsville, AL USA
Atomic-Based Combined Cycle Propulsion System and Method
Schmidt, George R., Inventor; Apr. 09, 2002; In English
Patent Info.: Filed 10 Apr. 2000; US-Patent-6,367,243; US-Patent-Appl-SN-546030; NASA-Case-MFS-31341; No Copyright; Avail: CASI; A02, Hardcopy

A method and system are provided for propelling an aerodynamic vehicle into space. The aerodynamic vehicle uses a nuclear-based thermal rocket (NTR) propulsion system capable of producing a hydrogen exhaust. A flow of air is introduced into the hydrogen exhaust to augment the thrust force at speeds of the vehicle up to approximately Mach 6. When the speed of the vehicle is approximately Mach 6 and the altitude of the vehicle is approximately 40 kilometers, the flow of air is stopped and the vehicle is propelled into space using only the NTR.
Official Gazette of the U.S. Patent and Trademark Office
Nuclear Propulsion; Spacecraft Launching; Rocket Thrust; Rocket Exhaust

20020049426 NASA Marshall Space Flight Center, Huntsville, AL USA
End-to-End Demonstrator of the Safe Affordable Fission Engine (SAFE) 30: Power Conversion and Ion Engine Operation
Hrbud, Ivana; VanDyke, Melissa; Houts, Mike; Goodfellow, Keith; Schafer, Charles, Technical Monitor; [2001]; In English; Space Technologies Applications International Forum Conference, 3-7 Feb. 2002, Albuquerque, NM, USA; No Copyright; Avail: CASI; A02, Hardcopy

The Safe Affordable Fission Engine (SAFE) test series addresses Phase 1 Space Fission Systems issues in particular

non-nuclear testing and system integration issues leading to the testing and non-nuclear demonstration of a 400-kW fully integrated flight unit. The first part of the SAFE 30 test series demonstrated operation of the simulated nuclear core and heat pipe system. Experimental data acquired in a number of different test scenarios will validate existing computational models, demonstrated system flexibility (fast start-ups, multiple start-ups/shut downs), simulate predictable failure modes and operating environments. The objective of the second part is to demonstrate an integrated propulsion system consisting of a core, conversion system and a thruster where the system converts thermal heat into jet power. This end-to-end system demonstration sets a precedent for ground testing of nuclear electric propulsion systems. The paper describes the SAFE 30 end-to-end system demonstration and its subsystems.
Author
End-to-End Data Systems; Fission; Ion Engines; Mathematical Models; Propulsion System Performance; Aerospace Systems

20020045526 Science Applications International Corp., Albuquerque, NM USA, Gray Research, Inc., Huntsville, AL USA
Evaluation of High-Performance Space Nuclear Electric Generators for Electric Propulsion Application
Woodcock, Gordon; Kross, Dennis A., Technical Monitor; [2002]; In English; Space Technology and Applications International Forum (STAIF), 3-7 Feb. 2002, Albuquerque, NM, USA
Contract(s)/Grant(s): GSA-GS-23F-0107J; NASA Order H-32738-D; No Copyright; Avail: CASI; A02, Hardcopy

Electric propulsion applications are enhanced by high power-to-mass ratios for their electric power sources. At multi-megawatt levels, we can expect thrust production systems to be less than 5 kg/kWe. Application of nuclear electric propulsion to human Mars missions becomes an attractive alternative to nuclear thermal propulsion if the propulsion system is less than about 10 kg/kWe. Recent references have projected megawatt-plus nuclear electric sources at specific mass values from less than 1 kg/kWe to about 5 kg/kWe. Various assumptions are made regarding power generation cycle (turbogenerator; MHD (magnetohydrodynamics)) and reactor heat source design. The present paper compares heat source and power generation options on the basis of a parametric model that emphasizes heat transfer design and realizable hardware concept. Pressure drop (important!) is included in the power cycle analysis, and MHD and turbogenerator cycles are compared. Results indicate that power source specific mass less than 5 kg/kWe is attainable, even if peak temperatures achievable are limited to 1500 K. Projections of specific mass less than 1 kg/kWe are unrealistic, even at the highest peak temperatures considered.
Author
Electric Propulsion; Nuclear Electric Propulsion; Nuclear Electric Power Generation; Spacecraft Propulsion

20020038204 NASA Glenn Research Center, Cleveland, OH USA
Status of Brayton Cycle Power Conversion Development at NASA GRC
Mason, Lee S.; Shaltens, Richard K.; Dolce, James L.; Cataldo, Robert L.; January 2002; In English, 7-7 Feb. 2002, Albuquerque, NM, USA; Original contains color illustrations
Contract(s)/Grant(s): RTOP 713-81-50
Report No.(s): NASA/TM-2002-211304; E-13108; NAS 1.15:211304; No Copyright; Avail: CASI; A03, Hardcopy

The NASA Glenn Research Center (GRC) is pursuing the development of Brayton cycle power conversion for various NASA initiatives. Brayton cycle power systems offer numerous advantages for space power generation including high efficiency, long life, high maturity, and broad scalability. Candidate mission applications include surface rovers and bases, advanced propulsion vehicles, and earth orbiting satellites. A key advantage is the ability for Brayton converters to span the wide range of power demands of future missions from several kilowatts to multi-megawatts using either solar, isotope, or reactor heat sources. Brayton technology has been under development by NASA since the early 1960's resulting in engine prototypes in the 2 to 15 kW-class that have demonstrated conversion efficiency of almost 30% and cumulative operation in excess of 40,000 hours. Present efforts at GRC are focusing on a 2 kW testbed as a proving ground for future component advances and operational strategies, and a 25 kW engine design as a modular building block for 100 kW-class electric propulsion and Mars surface power applications.
Author
Brayton Cycle; Nuclear Electric Power Generation; Nuclear Electric Propulsion

20020022207 NASA Glenn Research Center, Cleveland, OH USA
'2001: A Space Odyssey' Revisited: The Feasibility of 24 Hour Commuter Flights to the Moon Using NTR Propulsion with LUNOX Afterburners
Borowski, Stanley K.; Dudzinski, Leonard A.; December 2001; In English, 6-9 Jul. 1997, Seattle, WA, USA
Contract(s)/Grant(s): RTOP 953-20-0C

Report No.(s): NASA/TM-1998-208830/REV1; NAS 1.15:208830/REV1; E-11441/REV1; AIAA Paper 97-2956-Rev-1; No Copyright; Avail: CASI; A03, Hardcopy

The prospects for '24 hour' commuter flights to the Moon. similar to that portrayed in 2001: A Space Odyssey but on a more Spartan scale. are examined using two near term. 'high leverage' technologies-liquid oxygen (LOX)-augmented nuclear thermal rocket (NTR) propulsion and 'lunar-derived' oxygen (LUNOX) production. Iron-rich volcanic glass. or 'orange soil,' discovered during the Apollo 17 mission to Taurus-Littrow. has produced a 4% oxygen yield in recent NASA experiments using hydrogen reduction. LUNOX development and utilization would eliminate the need to transport oxygen supplies from Earth and is expected to dramatically reduce the size, cost and complexity of space transportation systems. The LOX-augmented NTR concept (LANTR) exploits the high performance capability of the conventional liquid hydrogen (LH2)-cooled NTR and the mission leverage provided by LUNOX in a unique way. LANTR utilizes the large divergent section of its nozzle as an 'afterburner' into which oxygen is injected and supersonically combusted with nuclear preheated hydrogen emerging from the engine's choked sonic throat-essentially 'scramjet propulsion in reverse.' By varying the oxygen-to-hydrogen mixture ratio, the LANTR engine can operate over a wide range of thrust and specific impulse (Isp) values while the reactor core power level remains relatively constant. The thrust augmentation feature of LANTR means that 'big engine' performance can be obtained using smaller. more affordable. easier to test NTR engines. The use of high-density LOX in place of low-density LH2 also reduces hydrogen mass and tank volume resulting in smaller space vehicles. An implementation strategy and evolutionary lunar mission architecture is outlined which requires only Shuttle C or 'in-line' Shuttle-derived launch vehicles, and utilizes conventional NTR-powered lunar transfer vehicles (LTVs), operating in an 'expendable mode' initially, to maximize delivered surface payload on each mission. The increased payload is dedicated to installing 'modular' LUNOX production units with the intent of supplying LUNOX to lunar landing vehicles (LLVs) and then LTVs at the earliest possible opportunity. Once LUNOX becomes available in low lunar orbit (LLO), monopropellant NTRs would be outfitted with an oxygen propellant module, feed system and afterburner nozzle for 'bipropellant' operation. Transition to a 'reusable' mission architecture now occurs with smaller, LANTR-powered LTVs delivering approximately 400% more payload on each piloted round trip mission than earlier expendable 'all LH2' NTR systems. As initial lunar outposts grow to eventual lunar settlements and LUNOX production capacity increases, the LANTR concept can enable a rapid 'commuter' shuttle capable of 24 hour 'one way' trips to and from the Moon. A vast deposit of 'iron-rich' volcanic glass beads identified at just one candidate site - located at the southeastern edge of Mare Serenitatis - could supply sufficient LUNOX to support daily commuter flights to the Moon for the next 9000 years'.
Author

Lunar Landing; Space Transportation System; Liquid Oxygen; Nuclear Propulsion; Lunar Soil

20010109423 NASA Marshall Space Flight Center, Huntsville, AL USA

Prospects for Nuclear Electric Propulsion Using Closed-Cycle Magnetohydrodynamic Energy Conversion

Litchford, R. J.; Bitteker, L. J.; Jones, J. E.; October 2001; In English

Report No.(s): NASA/TP-2001-211274; M-1027; NAS 1.60:211274; No Copyright; Avail: CASI; A04, Hardcopy

Nuclear electric propulsion (NEP) has long been recognized as a major enabling technology for scientific and human exploration of the solar system, and it may conceivably form the basis of a cost-effective space transportation system suitable for space commerce. The chief technical obstacles to realizing this vision are the development of efficient, high-power (megawatt-class) electric thrusters and the development of low specific mass (less than 1 kg/kWe) power plants. Furthermore, comprehensive system analyses of multimegawatt class NEP systems are needed in order to critically assess mission capability and cost attributes. This Technical Publication addresses some of these concerns through a systematic examination of multimegawatt space power installations in which a gas-cooled nuclear reactor is used to drive a magnetohydrodynamic (MHD) generator in a closed-loop Brayton cycle. The primary motivation for considering MHD energy conversion is the ability to transfer energy out of a gas that is simply too hot for contact with any solid material. This has several intrinsic advantages including the ability to achieve high thermal efficiency and power density and the ability to reject heat at elevated temperatures. These attributes lead to a reduction in system specific mass below that obtainable with turbine-based systems, which have definite solid temperature limits for reliable operation. Here, the results of a thermodynamic cycle analysis are placed in context with a preliminary system analysis in order to converge on a design space that optimizes performance while remaining clearly within established bounds of engineering feasibility. MHD technology issues are discussed including the conceptual design of a nonequilibrium disk generator and opportunities for exploiting neutron-induced ionization mechanisms as a means of increasing electrical conductivity and enhancing performance and reliability. The results are then used to make a cursory examination of piloted Mars missions during the 2018 opportunity.
Author

Magnetohydrodynamics; Nuclear Electric Propulsion; Energy Conversion; Systems Analysis; Thermodynamic Cycles

20010041281 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA

Saturn Ring Observer

Spilker, T. R.; Forum on Innovative Approaches to Outer Planetary Exploration 2001-2020; 2001, 80; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

Answering fundamental questions about ring particle characteristics, and individual and group behavior, appears to require close-proximity (a few km) observations. Saturn's magnificent example of a ring system offers a full range of particle sizes, densities, and behaviors for study, so it is a natural choice for such detailed investigation. Missions implementing these observations require post-approach Delta(V) of approximately 10 km/s or more, so past mission concepts called upon Nuclear Electric Propulsion. The concept described here reduces the propulsive Delta(V) requirement to as little as 3.5 km/s, difficult but not impossible for high-performance chemical propulsion systems. Additional information is contained in the original extended abstract.

Derived from text

Nuclear Electric Propulsion; Saturn Rings; Space Exploration; Propulsion System Performance

20010041268 Plus Ultra Technologies, Shoreham, NY USA

MITEE: A Compact Ultralight Nuclear Thermal Propulsion Engine for Planetary Science Missions

Powell, J.; Maise, G.; Paniagua, J.; Forum on Innovative Approaches to Outer Planetary Exploration 2001-2020; 2001, 66; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

A new approach for a near-term compact, ultralight nuclear thermal propulsion engine, termed MITEE (Miniature Reactor Engine) is described. MITEE enables a wide range of new and unique planetary science missions that are not possible with chemical rockets. With U-235 nuclear fuel and hydrogen propellant the baseline MITEE engine achieves a specific impulse of approximately 1000 seconds, a thrust of 28,000 newtons, and a total mass of only 140 kilograms, including reactor, controls, and turbo-pump. Using higher performance nuclear fuels like U-233, engine mass can be reduced to as little as 80 kg. Using MITEE, V additions of 20 km/s for missions to outer planets are possible compared to only 10 km/s for H2/O2 engines. The much greater V with MITEE enables much faster trips to the outer planets, e.g., two years to Jupiter, three years to Saturn, and five years to Pluto, without needing multiple planetary gravity assists. Moreover, MITEE can utilize in-situ resources to further extend mission V. One example of a very attractive, unique mission enabled by MITEE is the exploration of a possible subsurface ocean on Europa and the return of samples to Earth. Using MITEE, a spacecraft would land on Europa after a two-year trip from Earth orbit and deploy a small nuclear heated probe that would melt down through its ice sheet. The probe would then convert to a submersible and travel through the ocean collecting samples. After a few months, the probe would melt its way back up to the MITEE lander, which would have replenished its hydrogen propellant by melting and electrolyzing Europa surface ice. The spacecraft would then return to Earth. Total mission time is only five years, starting from departure from Earth orbit. Other unique missions include Neptune and Pluto orbiter, and even a Pluto sample return. MITEE uses the cermet Tungsten-UO2 fuel developed in the 1960's for the 710 reactor program. The W-UO2 fuel has demonstrated capability to operate in 3000 K hydrogen for many hours - a much longer period than the approximately one hour burn time for MITEE. Using this cermet fuel, and technology available from other nuclear propulsion programs, MITEE could be developed and ready for implementation in a relatively short time, i.e., approximately seven years. An overview description of the MITEE engine and its performance capabilities is provided.

Derived from text

Space Missions; Nuclear Propulsion; Spacecraft Power Supplies; Space Exploration

20010041261 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA

Nuclear Electric Propulsion for the Exploration of the Outer Planets

Noca, M.; Polk, J. E.; Lenard, R.; Forum on Innovative Approaches to Outer Planetary Exploration 2001-2020; 2001, 59; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

New power and propulsion technology efforts such as the DS-1 ion propulsion system demonstration and renewed interest in space nuclear power sources call for a reassessment of the mission benefits of Nuclear Electric Propulsion (NEP). In this study, a large emphasis has been placed in defining the NEP vehicle configuration and corresponding subsystem elements in order to produce an estimate of the vehicle's payload delivery capability which is as credible as possible. Both a 100 kWe and a 1 MWe system are defined. Various Outer Planet missions are evaluated using NEP, such as a Pluto Orbiter, a Europa Lander and Sample Return, attain/Saturn Sample Return and a Neptune Orbiter. Additional information is contained in the original extended abstract.

Derived from text

Nuclear Electric Propulsion; Space Exploration; Ion Propulsion; Spacecraft Power Supplies; Spacecraft Configurations; Propulsion System Configurations

20010041242 NASA Marshall Space Flight Center, Huntsville, AL USA
Space Fission Propulsion System Development Status
Houts, M.; Van Dyke, M. K.; Godfroy, T. J.; Pedersen, K. W.; Martin, J. J.; Dickens, R.; Williams, E.; Harper, R.; Salvail, P.; Hrbud, I., et al.; Forum on Innovative Approaches to Outer Planetary Exploration 2001-2020; 2001, 40; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

The world's first man-made self-sustaining fission reaction was achieved in 1942. Since then fission has been used to propel submarines, generate tremendous amounts of electricity, produce medical isotopes, and provide numerous other benefits to society. Fission systems operate independently of solar proximity or orientation, and are thus well suited for deep space or planetary surface missions. In addition, the fuel for fission systems (enriched uranium) is virtually non-radioactive. The primary safety issue with fission systems is avoiding inadvertent system start. Addressing this issue through proper system design is straight-forward. Despite the relative simplicity and tremendous potential of space fission systems, the development and utilization of these systems has proven elusive. The first use of fission technology in space occurred 3 April 1965 with the US launch of the SNAP-10A reactor. There have been no additional US uses of space fission systems. While space fission systems were used extensively by the former Soviet Union, their application was limited to earth-orbital missions. Early space fission systems must be safely and affordably utilized if we are to reap the benefits of advanced space fission systems. NASA's Marshall Space Flight Center, working with Los Alamos National Laboratory (LANL), Sandia National Laboratories, and others, has conducted preliminary research related to a Safe Affordable Fission Engine (SAFE). An unfueled core has been fabricated by LANL, and resistance heaters used to verify predicted core thermal performance by closely mimicking heat from fission. The core is designed to use only established nuclear technology and be highly testable. In FY01 an energy conversion system and thruster will be coupled to the core, resulting in an 'end-to-end' nuclear electric propulsion demonstrator being tested using resistance heaters to closely mimic heat from fission. Results of the SAFE test program will be presented. The applicability of a SAFE-powered electric propulsion system to outer planet science missions will also be discussed.
Derived from text
Fission; Nuclear Electric Propulsion; Space Missions; Spacecraft Power Supplies

20010041214 NASA Glenn Research Center, Cleveland, OH USA
Nuclear Thermal Rocket (NTR) Propulsion and Power Systems for Outer Planetary Exploration Missions
Borowski, S. K.; Cataldo, R. L.; Forum on Innovative Approaches to Outer Planetary Exploration 2001-2020; 2001, 13; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

The high specific impulse (I (sub sp)) and engine thrust generated using liquid hydrogen (LH2)-cooled Nuclear Thermal Rocket (NTR) propulsion makes them attractive for upper stage applications for difficult robotic science missions to the outer planets. Besides high (I (sub sp)) and thrust, NTR engines can also be designed for 'bimodal' operation allowing substantial amounts of electrical power (10's of kWe) to be generated for onboard spacecraft systems and high data rate communications with Earth during the course of the mission. Two possible options for using the NTR are examined here. A high performance injection stage utilizing a single 15 klbf thrust engine can inject large payloads to the outer planets using a 20 t-class launch vehicle when operated in an 'expendable mode'. A smaller bimodal NTR stage generating approx. 1 klbf of thrust and 20 to 40 kWe for electric propulsion can deliver approx. 100 kg using lower cost launch vehicles. Additional information is contained in the original extended abstract.
Derived from text
Nuclear Propulsion; Space Exploration; Nuclear Rocket Engines; Specific Impulse

20010028795 NASA Marshall Space Flight Center, Huntsville, AL USA
Magnetic Flux Compression Reactor Concepts for Spacecraft Propulsion and Power (MSFC Center Director's Discretionary Fund; Project No. 99-24), Part 1
Litchford, R. J.; Robertson, G. A.; Hawk, C. W.; Turner, M. W.; Koelfgen, S.; Litchford, Ron J., Technical Monitor; January 2001; In English
Report No.(s): NASA/TP-2001-210793/PT1; NAS 1.60:210793/PT1; M-995/PT1; No Copyright; Avail: CASI; A04, Hardcopy

This technical publication (TP) examines performance and design issues associated with magnetic flux compression reactor concepts for nuclear/chemical pulse propulsion and power. Assuming that low-yield microfusion detonations or chemical detonations using high-energy density matter can eventually be realized in practice, various magnetic flux compression concepts are conceivable. In particular, reactors in which a magnetic field would be compressed between an expanding detonation-driven plasma cloud and a stationary structure formed from a high-temperature superconductor are envisioned. Primary interest is accomplishing two important functions: (1) Collimation and reflection of a hot diamagnetic

plasma for direct thrust production, and (2) electric power generation for fusion standoff drivers and/or dense plasma formation. In this TP, performance potential is examined, major technical uncertainties related to this concept accessed, and a simple performance model for a radial-mode reactor developed. Flux trapping effectiveness is analyzed using a skin layer methodology, which accounts for magnetic diffusion losses into the plasma armature and the stationary stator. The results of laboratory-scale experiments on magnetic diffusion in bulk-processed type II superconductors are also presented.
Author
Magnetic Flux; Spacecraft Propulsion; Nuclear Propulsion; High Temperature Superconductors; Magnetic Diffusion

20010020215 NASA Marshall Space Flight Center, Huntsville, AL USA
Physical Limitations of Nuclear Propulsion for Earth to Orbit
Blevins, John A.; Patton, Bruce; Rhys, Noah O.; Schafer, Charles F., Technical Monitor; [2001]; In English; Joint Propulsion Conference, 8-11 Jul. 2001, Salt Lake City, UT, USA; No Copyright; Avail: Other Sources; Abstract Only

An assessment of current nuclear propulsion technology for application in Earth to Orbit (ETO) missions has been performed. It can be shown that current nuclear thermal rocket motors are not sufficient to provide single stage performance as has been stated by previous studies. Further, when taking a systems level approach, it can be shown that NTRs do not compete well with chemical engines where thrust to weight ratios of greater than I are necessary, except possibly for the hybrid chemical/nuclear LANTR (LOX Augmented Nuclear Thermal Rocket) engine. Also, the ETO mission requires high power reactors and consequently large shielding weights compared to NTR space missions where shadow shielding can be used. In the assessment, a quick look at the conceptual ASPEN vehicle proposed in 1962 in provided. Optimistic NTR designs are considered in the assessment as well as discussion on other conceptual nuclear propulsion systems that have been proposed for ETO. Also, a quick look at the turbulent, convective heat transfer relationships that restrict the exchange of nuclear energy to thermal energy in the working fluid and consequently drive the reactor mass is included.
Author
Nuclear Propulsion; Nuclear Rocket Engines; Space Missions; Earth Orbital Environments

20010016350 NASA Glenn Research Center, Cleveland, OH USA
Launch Vehicle Performance for Bipropellant Propulsion Using Atomic Propellants With Oxygen
Palaszewski, Bryan; November 2000; In English; 35th, 20-24 Jun. 1999, Los Angeles, CA, USA
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Report No.(s): NASA/TM-2000-209443; E-11927; NAS 1.15:209443; No Copyright; Avail: CASI; A03, Hardcopy

Atomic propellants for bipropellant launch vehicles using atomic boron, carbon, and hydrogen were analyzed. The gross liftoff weights (GLOW) and dry masses of the vehicles were estimated, and the 'best' design points for atomic propellants were identified. Engine performance was estimated for a wide range of oxidizer to fuel (O/F) ratios, atom loadings in the solid hydrogen particles, and amounts of helium carrier fluid. Rocket vehicle GLOW was minimized by operating at an O/F ratio of 1.0 to 3.0 for the atomic boron and carbon cases. For the atomic hydrogen cases, a minimum GLOW occurred when using the fuel as a monopropellant (O/F = 0.0). The atomic vehicle dry masses are also presented, and these data exhibit minimum values at the same or similar O/F ratios as those for the vehicle GLOW. A technology assessment of atomic propellants has shown that atomic boron and carbon rocket analyses are considered to be much more near term options than the atomic hydrogen rockets. The technology for storing atomic boron and carbon has shown significant progress, while atomic hydrogen is not able to be stored at the high densities needed for effective propulsion. The GLOW and dry mass data can be used to estimate the cost of future vehicles and their atomic propellant production facilities. The lower the propellant's mass, the lower the overall investment for the specially manufactured atomic propellants.
Author
Nuclear Propulsion; Propellants; Oxygen; Atoms

20000103873 Boeing Co., Huntsville, AL USA
Human Mars Transportation Applications Using Solar Electric Propulsion
Donahue, Benjamin B.; Martin, Jim; Potter, Seth; Henley, Mark; Carrington, Connie, Technical Monitor; [2000]; In English; Space, 19-21 Sep. 2000, Long Beach, CA, USA; Original contains color illustrations
Contract(s)/Grant(s): NAS8-98244
Report No.(s): AIAA Paper 2000-5360; Copyright; Avail: CASI; A03, Hardcopy

Advanced solar electric power systems and electric propulsion technology constitute viable elements for conducting human Mars transfer missions that are roughly comparable in performance to similar missions utilizing alternative high thrust

systems, with the one exception being their inability to achieve short Earth-Mars trip times. A modest solar electric propulsion human Mars scenario is presented that features the use of conjunction class trajectories in concert with pre-emplacement of surface assets that can be used in a series of visits to Mars. Major elements of the Mars solar electric transfer vehicle can be direct derivatives of present state-of-the-art Solar array and electric thruster systems. During the study, several elements affecting system performance were evaluated, including varying Earth orbit altitude for departure, recapturing the transfer stage at Earth for reuse, varying power system mass-to-power ratio, and assessing solar array degradation on performance induced by Van Allen belt passage. Comparisons are made to chemical propulsion and nuclear thermal propulsion Mars vehicles carrying similar payloads.
Author
Solar Electric Propulsion; Mars Missions; Solar Arrays; Nuclear Propulsion; Chemical Propulsion; Electric Propulsion

20000096503 NASA Marshall Space Flight Center, Huntsville, AL USA
Nuclear Pulse Propulsion: Orion and Beyond
Schmidt, George R.; Bonometti, J. A.; Morton, P. J.; [2000]; In English; 36th, 16-19 Jul. 2000, Huntsville, AL, USA
Report No.(s): AIAA Paper 2000-3856; Copyright; Avail: CASI; A02, Hardcopy

The race to the Moon dominated manned space Fight during the 1960's. and culminated in Project Apollo. which placed 12 humans on the Moon Unbeknownst to the public at that time, several U.S. Government agencies sponsored a project that could have conceivably, placed 150 people on the Moon and eventually sent crewed expeditions to Mars and the outer Planets. These feats could have possibly been accomplished during, the same period of time as Apollo. and for approximately the same cost. The project. code-named Orion. featured an extraordinary propulsion method known n as Nuclear Pulse The concept is probably as radical today as t was at the down of the space age. However its development appeared to he so promising that it was only by Political and non-technical considerations that it was not used to extend humanity reach throughout the solar system and quite possible to the stars. This paper discusses the rationale for nuclear pulse propulsion and presents a general history of the concept. focusing particularly on Project Orion. It describes some of the reexaminations being done in this area and discusses some of the new ideas that could mitigate many of the political and environmental issues associated with the concept.
Author
Nuclear Propulsion; Moon; Expeditions

20000093253 Academy of Sciences (USSR), Moscow, USSR
A Feasibility Study and Experimental Evaluation on MHD Acceleration for Application to Advanced Propulsion and Hypervelocity Ground Testing
Bityurin, Valentine A.; Jul. 2000; In English
Contract(s)/Grant(s): F61775-00-W-E031
Report No.(s): AD-A379923; EOARD-SPC-00-4031; No Copyright; Avail: CASI; A03, Hardcopy

This report results from a contract tasking Russian Academy of Sciences as follows: The contractor will conduct initial feasibility and analysis studies on the application of MHD accelerator for propulsion and flow acceleration. The overall objective of the proposed project is to perform preliminary testing in order to evaluate an experimental MHD accelerator laboratory that can be used in the future for both experimentation into MHD propulsion and as a hypervelocity wind tunnel for experiments into hypersonic flow and flight control system within the confines of the proposed program, the contractor seeks to: 1) analyze and report on the potential capability of MHO acceleration assisted advanced propulsion and to provide quasi-steady state hypervelocity ground tests; 2) evaluate an existing experimental MHD accelerator laboratory for experimental testing and 3) develop an experimental plan for conduct of an open demonstration experiment.
DTIC
Magnetohydrodynamics; Nuclear Propulsion; Hypersonic Flow; Feasibility Analysis; Plasma Acceleration; High Temperature Gases

20000091022 NASA Marshall Space Flight Center, Huntsville, AL USA
Fission Technology for Exploring and Utilizing the Solar System
Houts, Mike; VanDyke, Melissa; Godfroy, Tom; Pedersen, Kevin; Martin, James; Dickens, Ricky; Salvail, Pat; Hrbub, Ivana; Schmidt, George R., Technical Monitor; [2000]; In English; Joint Propulsion, 17-19 Jul. 2000, Huntsville, AL, USA; No Copyright; Avail: CASI; A01, Hardcopy

Fission technology can enable rapid, affordable access to any point in the solar system. Potential fission-based

transportation options include bimodal nuclear thermal rockets, high specific energy propulsion systems, and pulsed fission propulsion systems. In-space propellant re-supply enhances the effective performance of all systems, but requires significant infrastructure development. Safe, timely, affordable utilization of first-generation space fission propulsion systems will enable the development of more advanced systems. First generation space systems will build on over 45 years of US and international space fission system technology development to minimize cost,
Author
Aerospace Engineering; Fission; Propulsion System Configurations; Propulsion System Performance; Propellants; Spacecraft Propulsion; Nuclear Propulsion

20000085870 Space America, Inc., Huntsville, AL USA
In-Space Transportation Propulsion Architecture Assessment
Woodcock, Gordon; Aug. 15, 2000; In English; Diskette: 1 3.5-inch DSHD diskette
Contract(s)/Grant(s): NASA Order H-32723-D
Report No.(s): NONP-NASA-DK-2000118312; No Copyright; Avail: CASI; A03, Hardcopy

Almost all space propulsion development and application has been chemical. Aerobraking has been used at Venus and Mars, and for entry at Jupiter. One electric propulsion mission has been flown (DS-1) and electric propulsion is in general use by commercial communications satellites for stationkeeping. Gravity assist has been widely used for high-energy missions (Voyager, Galileo, Cassini, etc.). It has served as a substitute for high-energy propulsion but is limited in energy gain, and adds mission complexity as well as launch opportunity restrictions. It has very limited value for round trip missions such as humans to Mars and return. High-energy space propulsion has been researched for many years, and some major developments, such as nuclear thermal propulsion (NTP), undertaken. With the exception of solar electric propulsion at a scale of a few kilowatts, high-energy space propulsion has never been used on a mission. Most mission studies have adopted TRL 6 technology because most have looked for a near-term start. The current activity is technology planning aimed at broadening the options available to mission planners. Many of the illustrations used in this report came from various NASA sources; their use is gratefully acknowledged.
Author
Transportation; Commercial Spacecraft; Nuclear Propulsion; Solar Electric Propulsion; Technological Forecasting

20000074671 NASA Marshall Space Flight Center, Huntsville, AL USA
In Space Nuclear Power as an Enabling Technology for Deep Space Exploration
Sackheim, Robert L.; Houts, Michael; [2000]; In English; 36th, 16-19 Jul. 2000, Huntsville, AL, USA; No Copyright; Avail: Other Sources; Abstract Only

Deep Space Exploration missions, both for scientific and Human Exploration and Development (HEDS), appear to be as weight limited today as they would have been 35 years ago. Right behind the weight constraints is the nearly equally important mission limitation of cost. Launch vehicles, upper stages and in-space propulsion systems also cost about the same today with the same efficiency as they have had for many years (excluding impact of inflation). Both these dual mission constraints combine to force either very expensive, mega systems missions or very light weight, but high risk/low margin planetary spacecraft designs, such as the recent unsuccessful attempts for an extremely low cost mission to Mars during the 1998-99 opportunity (i.e., Mars Climate Orbiter and the Mars Polar Lander). When one considers spacecraft missions to the outer heliopause or even the outer planets, the enormous weight and cost constraints will impose even more daunting concerns for mission cost, risk and the ability to establish adequate mission margins for success. This paper will discuss the benefits of using a safe in-space nuclear reactor as the basis for providing both sufficient electric power and high performance space propulsion that will greatly reduce mission risk and significantly increase weight (IMLEO) and cost margins. Weight and cost margins are increased by enabling much higher payload fractions and redundant design features for a given launch vehicle (higher payload fraction of IMLEO). The paper will also discuss and summarize the recent advances in nuclear reactor technology and safety of modern reactor designs and operating practice and experience, as well as advances in reactor coupled power generation and high performance nuclear thermal and electric propulsion technologies. It will be shown that these nuclear power and propulsion technologies are major enabling capabilities for higher reliability, higher margin and lower cost deep space missions design to reliably reach the outer planets for scientific exploration.
Author
Interplanetary Spacecraft; Mission Planning; Nuclear Electric Propulsion; Nuclear Reactors; Propulsion System Configurations; Reactor Design; Reactor Technology

20000067640 NASA Marshall Space Flight Center, Huntsville, AL USA

Propulsion Options For Interstellar Exploration

Johnson, Les; Leifer, Stephanie; [2000]; In English; 36th, 17-19 Jul. 2000, Huntsville, AL, USA; No Copyright; Avail: Other Sources; Abstract Only

NASA is considering missions to explore near-interstellar space (40 - 250 Astronomical Units) early in the next decade as the first step toward a vigorous interstellar exploration program. A key enabling technology for such an ambitious science and exploration effort is a propulsion system capable of providing fast trip times, yet which has low enough mass to allow for the use of inexpensive launch vehicles. Advanced propulsion technologies that might support the First interstellar precursor mission by the end of the first decade of the new millennium include solar sails and nuclear electric propulsion. Solar sails and electric propulsion are two technology areas that may hold promise for the next generation of interstellar precursor missions as well - perhaps a thousand astronomical units traveled in a professional lifetime. Future missions to far beyond the Heliosphere will require the development of propulsion technologies that are only at the conceptual stage today. For years, the scientific community has been interested in solar sail and electric propulsion technologies to support robotic exploration of the solar system. Progress in thin-film materials fabrication and handling, and advancement in technologies that may enable the deployment of large sails in space are only now maturing to the point where ambitious interstellar precursor missions using sails can be considered. Xenon ion propulsion is now being demonstrated for planetary exploration by the Deep Space 1 mission. The primary issues for the adaptation of electric propulsion to interstellar precursor applications include the development of low specific mass nuclear power systems, engine lifetime, and high power operation. Recent studies of interstellar precursor mission scenarios that use these propulsion systems will be described, and the range of application of each technology will be explored.

Author

Interstellar Space; Space Exploration; Propulsion System Configurations; Propulsion System Performance

20000039473 NASA Marshall Space Flight Center, Huntsville, AL USA

Magnetic Flux Compression Concept for Nuclear Pulse Propulsion and Power

Litchford, Ronald J.; [2000]; In English; 2nd, 5-7 Apr. 2000, Moscow, Russia; No Copyright; Avail: Other Sources; Abstract Only

The desire for fast, efficient interplanetary transport requires propulsion systems having short acceleration times and very high specific impulse attributes. Unfortunately, most highly efficient propulsion systems which are within the capabilities of present day technologies are either very heavy or yield very low impulse such that the acceleration time to final velocity is too long to be of lasting interest, One exception, the nuclear thermal thruster, could achieve the desired acceleration but it would require inordinately large mass ratios to reach the range of desired final velocities. An alternative approach, among several competing concepts that are beyond our modern technical capabilities, is a pulsed thermonuclear device utilizing microfusion detonations. In this paper, we examine the feasibility of an innovative magnetic flux compression concept for utilizing microfusion detonations, assuming that such low yield nuclear bursts can be realized in practice. In this concept, a magnetic field is compressed between an expanding detonation driven diamagnetic plasma and a stationary structure formed from a high temperature superconductor (HTSC). In general, we are interested in accomplishing two important functions: (1) collimation of a hot diamagnetic plasma for direct thrust production; and (2) pulse power generation for dense plasma ignition. For the purposes of this research, it is assumed that rnicrofusion detonation technology may become available within a few decades, and that this approach could capitalize on recent advances in inertial confinement fusion ICF) technologies including magnetized target concepts and antimatter initiated nuclear detonations. The charged particle expansion velocity in these detonations can be on the order of 10 (exp 6)- 10 (exp 7) meters per second, and, if effectively collimated by a magnetic nozzle, can yield the Isp and the acceleration levels needed for practical interplanetary spaceflight. The ability to ignite pure fusion micro-bursts with reasonable levels of input energy is an equally challenging scientific problem. It remains to be seen, however, whether an effective ignition driver can be developed which meets the requirements for practical spaceflight application (namely high power density, compactness, low weight, and low cost). In this paper, system level performance and design issues are examined including generator performance, magnetic flux compression processes, magnetic diffusion processes, high temperature superconductor (HTSC) material properties, plasmadynamic processes, detonation plasma expansion processes, magnetohydrodynamic instabilities, magnetic nozzle performance, and thrust production performance. Representative generator performance calculations based on a simplified skin layer formulation are presented as well as the results of exploratory small-scale laboratory experiments on magnetic flux diffusion in HTSC materials. In addition, planned follow-on scientific feasibility experiments are described which utilize high explosive detonations and high energy gas

discharges to simulate the plasma conditions associated with thermonuclear micro-detonations.
Author
Magnetic Flux; Nuclear Propulsion; Propulsion System Performance; Plasmas (Physics); Power Efficiency; Compression Loads

20000033616 NASA Marshall Space Flight Center, Huntsville, AL USA
Space Transportation in the New Millennium
McGill, Preston; [2000]; In English, 2 Feb. 2000, Marianna, FL, USA; No Copyright; Avail: CASI; A03, Hardcopy

This paper presents viewgraphs of Space Transportation in the New Millennium. Pictures are shown of the space shuttle lift Off, rocket motion, the space shuttle main engine, the space shuttle external tank, the space shuttle solid rocket booster, the X-33, X-34, X-37, X-38, magnetic levitation, the rbcc, nuclear thermal propulsion, anti-matter propulsion system, the NTP or anti-matter concept vehicles, and the Space Elevator.
CASI
Spacecraft Design; Space Shuttles; Space Transportation System; Spacecraft Propulsion; Rocket Engines

Subject Terms

NUCLEAR FISSION

NUCLEAR FUEL ELEMENTS

NUCLEAR FUELS

NUCLEAR FUSION

NUCLEAR POWER REACTORS

NUCLEAR PROPULSION

NUCLEAR REACTOR CONTROL

NUCLEAR REACTORS

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